Competition and Innovation: The Breakup of IG Farben*

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December 2, 2024

Abstract

The relationship between competition and innovation is difficult to disentangle, as exogenous variation in market structure is rare. The 1952 breakup of Germany's leading chemical company, IG Farben, represents such a disruption. After the Second World War, the Allies occupying Germany imposed the breakup because of IG Farben's importance for the German war economy instead of standard antitrust concerns. In technologies where the breakup reduced concentration by creating multiple successor firms with technological capabilities, patenting increased strongly, predominantly by domestic firms unrelated to IG Farben. The increase in patenting is not driven by alternative explanations such as product market competition, an increased propensity to patent, duplication of research, or mobility of IG Farben inventors. Instead, the breakup seems to have increased innovation among the IG Farben successors, which then spilled over to the broader industry: The IG Farben's successors also increased their patenting activities and specialized relative to the pre-breakup period.

KEYWORDS: Innovation, Competition, Merger, Antitrust, IG Farben.
JEL: O31, L44, N44

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1 Introduction

Innovation is a key driver of economic growth, as it allows firms to increase their productivity and grow by capturing and creating markets with new products or improved variants. Superior innovation performance by superstar firms has long been highlighted by Schumpeterian (1942) arguments and has recently been linked to modern concentration trends (e.g. Crouzet and Eberly, 2019; Autor, Dorn, Katz, et al., 2020). In contrast, overly large concentration may decrease incumbents' innovation incentives (Arrow, 1962; Aghion et al., 2005) and, with that, harm growth and societal welfare. Empirically, however, the effect of competition on innovation is difficult to determine, as both are highly endogenous, and exogenous variation in technology and market structure is rare. Further, innovation effects could be driven by competition for existing or, via competition in technology space and spillovers, future product markets. To understand effects and mechanisms, studying antitrust interventions that reshape industry structure on a large scale represents a way forward. However, such cases are few and far between (Lamoreaux, 2019), and pertinent cases, such as the breakups of Standard Oil and AT&T, were themselves motivated by concerns about competition and innovation.

In this study, I exploit the 1952 breakup of Germany's largest chemical company by the Allied Powers outside of standard antitrust practice (Stokes, 1988). The breakup target, IG Farben, was one of the most innovative German companies. Three of its scientists won Nobel prizes - one for the world's first antibiotic. It played an outsized role in the German innovation system, responsible for 5.9% of all patents by German inventors, up to 16.7% in chemistry. IG Farben was also of crucial relevance for the German war machine (Hayes, 1987; Plumpe, 1990). The victorious Allies recognized this and IG Farben's economic influence as undue political potential. IG Farben's crimes, including its major involvement at the Auschwitz concentration camp, fueled this negative perception. After a year-long deliberation, the Allies decided on a breakup largely following their occupation zones in Germany. Three large successors - BASF, Bayer, and Hoechst[1] - were created, as well as a dozen smaller businesses (Stokes, 1994).

I start by demonstrating that the breakup created competition in significant parts of product- and technology space using data from historical product catalogs and patent documents. The first post-breakup product catalog of 1952 lists 3,192 products, of which IG Farben successors supplied 1,296. For 34% of IG Farben products, more than one successor was present, indicating widespread product-level competition. Products, especially IG Farben products, are typically also supplied by several other firms. For a subset of products, I obtain price data and the chemical structure. Products supplied by IG Farben tend to be more basic, with lower prices and simpler chemical composition. After the breakup, prices for products with post-breakup competition

[1]BASF and Bayer continue to exist as global corporations under the same names. After a series of mergers in the late 1990s, Hoechst is now part of Sanofi, Celanese, and others.

drop by 6-8%.[2] To delineate technology space, I rely on the historical German technology classification. In a number of technology classes, more than one of the IG Farben successors' R&D laboratories had a substantial presence. During its existence, IG Farben's leadership had attempted to coordinate and rationalize (Feldenkirchen, 1987), and joint patenting between major R&D locations had increased (around 2% of patents in 1930-1935 compared to 0.7% in 1920-1925). Separating IG Farben into successors is associated with substantial decreases of concentration (HHI) within the technology classes by, on average, 317 (1,226 in the top 25% classes with the largest changes).

In the main body of the paper, I analyze how the breakup affected innovation output in the German chemical industry and find that innovation in technologies exposed to the IG Farben breakup increased strongly and persistently compared to other chemical technologies. I proxy breakup exposure with the concentration change resulting from the breakup of IG Farben (Nocke and Whinston, 2022), which is directly related to the extent to which the breakup created multiple successors with R&D capabilities in a given technology. I avoid contamination of the exposure measure with wartime events and post-breakup adjustments by focusing on a pre-war measure: the hypothetical change if the breakup had been implemented before the war according to the eventual breakup structure. In regression analyses, I find parallel patenting trends in exposed and unaffected technologies before 1952. After the breakup, however, patenting in exposed technologies increasingly diverged, indicating a sizeable positive innovation effect of about 70% for a typical technology, or about 35 additional patents per class and year. In subsequent analyses, I investigate the role of various channels, including product market exposure to the breakup, inventor labor markets, the propensity to patent, and duplication.

The analysis employs German patent data to measure innovation outputs in technologies and by firms, uses fine-grained product-level data to capture market structure, and links products and patents using in-text mentions. I begin with scanned grant documents and historical product catalogs and apply image processing, pattern recognition, and machine learning methods. From patents, I recover applicant, inventor, and technology class information so far unavailable at a comparable scale. As standard measures for heterogeneity between patents, such as forward citations, are unavailable, I introduce quality measures based on patent texts. Analogous to citations, these quality measures describe the importance of a patent for subsequent patents and relative to previous patents (cf. Kelly et al., 2021). Finally, I link patents with products using in-text mentions based on patent fulltexts and product catalog entries to distinguish between the

[2]For chemical substances that can largely be seen as homogeneous intermediate products, this is consistent with the literature (Marshall and Parra, 2019; Dafny, 2009; Ashenfelter, Hosken, and Weinberg, 2013). However, as the historical product catalogs listed existing products that were in common use in the chemical industry, the moderate price effects may understate the full impact of the breakup.

technology and product market dimensions. Making this novel data available, either newly or much improved, is also a contribution of this study.

Identification relies on the assumption of parallel trends for continuous exposure variables (Callaway, Goodman-Bacon, and Sant'Anna, 2021), which is consistent with the data. A major concern is that exposure might reflect unobserved differences in technological potential, which could have led to larger exposure due to increased investments by IG Farben. However, the results are robust to alternative measures of breakup exposure that focus on the geographic distribution of pre-war patents within IG Farben. This focus reduces the influence of the absolute investment amount. A second assumption maintains that the IG Farben shock is separable from other contemporary changes. Reassuringly, the timing of the effect suggests that it was unrelated to war-related changes. Confounding factors would need to correlate closely to the geographic structure of IG Farben across occupation zones. Instead, most factors are large-scale developments and affect the entire chemical industry. Nonetheless, I test the impact of many parallel events and include control variables for war destruction, dismantlement, the German separation, among others. If factors are immeasurable, I discuss their potential impact based on the historical literature.

To better understand the mechanisms, I decompose the effects by applicant groups. First, results are similar when counting only patents without IG Farben association, indicating that non-IG Farben firms drive the main results. Descriptively, post-war patenting by the IG Farben successors begins at the pre-war level and increases after the breakup, both in absolute terms and in comparison with a synthetic control. Positive innovation effects of the breakup for both the IG Farben successors and affected technologies suggest that the innovation responses of IG Farben and other firms were strategic complements, and may have been related to technology spillovers from IG Farben to the wider industry. Next, I test whether the effect is explained by domestic or foreign patenting. Patenting by foreign applicants in Germany increased after the war, but the increase occurred discretely and prior to the finalization of IG Farben's breakup. Therefore, the changes in foreign patenting are likely unrelated. Domestic applicants drive the majority of the increased patenting after 1952 – consistent with spillovers, which tend to be more likely national than global (Jaffe, Trajtenberg, and Henderson, 1993).

A second set of potential mechanisms is related to potential increases in the propensity to patent and duplication of research. First, increased competition could also increase the value of patents, thereby changing the propensity to patent a given invention. To test this, I distinguish between raw patent counts and quality-weighted counts, which rely on an adjusted application of Kelly et al. (2021)'s approach to text-based measurement of patent quality as comprehensive patent citation data is absent in the period of interest. Indeed, raw patent counts increase immediately after the breakup, whereas the quality-weighted count rises gradually.

Average quality decreases immediately after the breakup but normalizes within a few years. A quality-quantity trade-off is introduced, but only in the short run. Second, the breakup could have led to duplication of research within technologies.[3] To test this, I exclude patents highly similar to recent patents in the same technology, as benchmarked by 'patents of addition,' a type of patent comparable to continuation/continuation-in-part patents in today's US patent system. Excluding highly similar patents, the estimated effects decrease only marginally. In an extension, I propose indicators of technology-level specialization based on patent text similarity (Arts, Cassiman, and Gomez, 2018). While IG Farben's successors continued to patent in the same technology classes, their research specialized within them. On an aggregate level, the dispersion of research within affected technology classes increases.[4]

Next, I test whether competition in existing product markets, rather than in technology space, could account for the increases in innovation. I leverage fine-grained historical data on the suppliers of thousands of chemical products, which allows me to identify which products were exposed to increased competition among IG Farben successors in existing product markets. As discussed, many products were supplied by two or more IG Farben successors immediately after the breakup, which was associated with price decreases. This data allows me to create indicators for the technology-level importance of breakup-related product market competition or to analyze innovation effects in a product-level panel. The results of both approaches are consistent in that competition in existing product markets is not a primary factor for the innovation increase (Bloom, Schankerman, and Van Reenen, 2013). Instead, the innovation increase resulting from competition in technology space likely targeted future markets. Consistent with this, towards the end of the sample period, as much as half of the IG Farben successors' revenue stemmed from new products.

Finally, I show that the results are not driven by a labor market channel, specifically moves of inventors do not seem to be a key mechanism. Inventors may have moved away from IG Farben due to changes in reputation or changes in research conditions, which could have increased allocation efficiency at IG Farben while increasing research output at non-IG Farben firms. To test this, I first document the extent to which inventors moved, and then attempt to pinpoint the effect of such moves. Descriptively, inventors' affiliations on patents reveal that few inventors who had worked for IG Farben before the war later changed affiliation to join other companies. I also consult membership lists of the German Chemical Society to exclude the possibility that

[3]Project choice, diversity, and duplication of research have been discussed theoretically (Denicolò and Polo, 2018; Letina, 2016; Gilbert, 2019; Bryan, Lemus, and Marshall, 2022), but empirical analysis has been limited.

[4]In the context of IG Farben's breakup, the successor companies competed in many fields, ranging from the production of basic chemicals to the cutting-edge technologies of the time. For example, all three successors strongly invested in plastics and synthetic fiber research, which often yielded different approaches and, consequently, products. At the same time, considerable specialization remained. So, while Bayer and Hoechst continued to excel in pharmaceutical research, BASF's entry into this field remained fraught with problems (Teltschik, 1992).

non-patenting inventors play a role, but do not find many moves at the time of the breakup, either. In regression analyses, excluding inventors working for IG Farben before the war does not change the results. Finally, firms which employed IG Farben inventors following the breakup did not experience a pronounced increase in patenting.

In summary, the breakup impacted both IG Farben and non-IG Farben firms by inducing competition in existing product markets and, via technology space, competition for future markets. To understand the impact on the IG Farben successors themselves, the analogous perspective of a merger is helpful. Both a breakup and a merger constitute a change in control rights over production assets of the merged entity, but in the opposite direction.[5] Theoretically, a merger's innovation effect on the combined firms is ambiguous: it depends on the particular market structure and the presence of merger efficiencies (Marshall and Parra, 2019; Jullien and Lefouili, 2018; Gilbert, 2020).[6] The results in this paper indicate that innovation output by the IG Farben successors increased, yet the increased patenting did not specifically focus on existing product markets where the breakup had increased competition.

In contrast, non-IG Farben firms are affected by the breakup through changes to IG Farben, either through responses to competition or via technology spillovers resulting from IG Farben's innovation output itself. Direct effects from competition increases in existing markets may have the same (Haucap, Rasch, and Stiebale, 2019) or the opposite (Federico, Langus, and Valletti, 2018; Bloom, Schankerman, and Van Reenen, 2013) direction as for IG Farben. Further, the breakup could have increased the contestability of markets directly by ending IG Farben's ability to prevent entry of or delineate markets with other incumbents (as Haber, 1971, p. 287 suggests). Then, the breakup would increase incentives to innovate and enter for other firms – but primarily focused on existing markets. Alternatively, indirect effects include technology spillovers, which would affect firms operating in the same technology space as IG Farben (Bloom, Schankerman, and Van Reenen, 2013). Based on the new ideas, others could develop downstream products or introduce competing approaches. Such spillovers, although difficult to pinpoint, have been shown to be large (Arora, Belenzon, and Sheer, 2021; Myers and Lanahan, 2022). The results in this paper indicate that competition in technology space increased innovation efforts of non-IG Farben and predominantly German firms. Yet, the increased innovation output was

[5]As an antitrust tool, a breakup would aim to induce long-lasting competition. In contrast, companies can also be broken up along business lines, as in corporate de-mergers, inducing little to no change in competition. In the case of IG Farben, the breakup induced considerable (horizontal) competition at the technology and product level, see Section 4.1.

[6]Marshall and Parra (2019) study innovation in response to an increase in the number of firms and argue that the sign of the innovation effect depends on the particular market structure. However, a breakup leaves R&D and production assets unchanged and increases competition by dividing control rights, which is conceptually close to a merger in reverse (Federico, Scott Morton, and Shapiro, 2019). For example, Federico, Langus, and Valletti (2017, 2018) argue that decreased innovation incentives likely dominate, inducing a negative competition-innovation relationship. In contrast, e.g., technology sharing between merging firms increases their innovation incentives by raising the value of a given innovation (Denicolò and Polo, 2021).

not primarily related to competition in existing product markets. Taken together, these results suggest an important role of technology spillovers.

With this study, I contribute to the empirical literature on competition and innovation (Gilbert, 2006; Cohen, 2010; Gilbert, 2020). Research on competition and innovation enjoys a long tradition, going back at least to Schumpeter (1942) and Arrow (1962). The dynamic relationship between industry structure (competition) and industry outcomes complicates empirical work, especially reduced-form. Structure likely influences performance and vice versa. In the absence of direct shocks to market structure, authors have analyzed other interventions that imply competition changes, such as the removal of trade barriers, and found ambiguous innovation results (Shu and Steinwender, 2018). In contrast, the breakup of IG Farben presents a rare exogenous change in the structure of a R&D-intensive sector and is particularly instructive due to its size and nature, which allows studying mechanisms in detail. First, in contrast to most other breakups, IG Farben's fate was decided based on political rather then antitrust considerations. Specifically, the breakup was not intended to stimulate German innovation. Second, the nature of the breakup – creating multiple successors with overlapping technological capabilities as well as product market exposure – provides a rare direct shock to competition and allows insights into which factors mattered for the innovation increase.

This study also contributes to the literature studying the history of antitrust, particularly regarding breakups of large corporations (Lamoreaux, 2019). Most closely related are Watzinger and Schnitzer (2022), who study the 1984 breakup of the Bell system following a lengthy intervention process by antitrust authorities. In the case of Bell, the vertical aspect of the breakup and the resulting contestability of product markets were central, whereas the restructuring of the R&D units played only a comparatively minor role.[7] In contrast, the IG Farben breakup was primarily horizontal and changes to R&D units were central. Other studies have focused on historical episodes of government-mandated compulsory licensing of patents and found innovation increases due to subsequent entry into affected technology fields (Baten, Bianchi, and Moser, 2017; Moser and Voena, 2012; Watzinger, Fackler, et al., 2020). The IG Farben breakup did not involve compulsory licensing, patent rights remained in place.[8]

[7]As a result, Watzinger and Schnitzer (2022) define exposure to the breakup as any technological activity of Bell in a technology and find large innovation increases of non-Bell firms following the breakup. In line with this, the innovation output of Bell's successors themselves decreased. See also Olley and Pakes (1996) and Datta (2003) for earlier analyses of productivity effects following the breakup of the Bell system. In an appendix, Watzinger and Schnitzer (2022) also study the breakup of Standard Oil.

[8]Royalty-free licensing was introduced among the IG Farben successors, which essentially maintained the pre-breakup situation and was intended to reduce adjustment frictions. Firms unrelated to IG Farben did not benefit. Overall, compulsory licensing is an important antitrust tool, but best understood in line with research on the exogenous removal of patent rights themselves (Galasso and Schankerman, 2015; Gaessler et al., 2024), rather then the restructuring of technological capabilities.

The literature on mergers and innovation is closely related. Although mergers and breakups differ, many arguments on the effect of mergers – such as the trade-off between potential efficiencies with disincentives arising from reduced competition – can be reversed and, as a benchmark, applied to breakups. When analyzing mergers, studies have relied on matching methods combined with difference in differences and sometimes instrumental variable analysis to estimate effects. The resulting evidence is mixed, with either no (Danzon, Epstein, and Nicholson, 2007) or negative innovation effects (Ornaghi, 2009; Szücs, 2014; Haucap, Rasch, and Stiebale, 2019) of mergers. However, the occurrence of mergers and litigation by antitrust authorities are selective (Carlton, 2009). In this study, I instead estimate effects within one event, which differentially affected a broad range of markets and technologies. In particular, I highlight the importance of competitor responses induced through technology spillovers, which have received less attention from the literature (Haucap, Rasch, and Stiebale, 2019; Arora, Belenzon, and Sheer, 2021). Other studies descriptively identify important stylized features and consequences of mergers (Cassiman et al., 2005; Cunningham, Ederer, and Ma, 2021). A third strand relies on structural estimation to study competition and innovation surrounding mergers (Goettler and Gordon, 2011; Igami and Uetake, 2020).

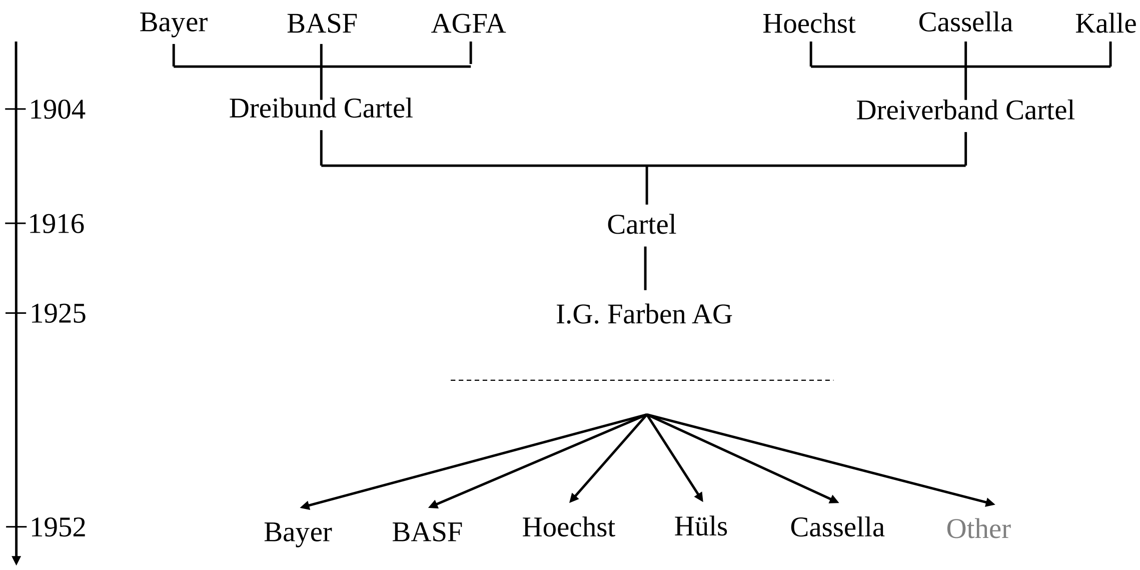
The remainder of the paper is organized as follows. Section 2 discusses the history of IG Farben, and Section 3 introduces data sources. Section 4 first introduces descriptive evidence on product-level breakup exposure, discusses price effects, and then introduces measures of the breakup in technology space. Section 5 discusses the empirical strategy. Section 6 studies innovation effects, including product-patent linkages and evidence on the product market channel. Section 7 describes the subsequent development of the IG Farben successors, and Section 8 concludes.

2 Historical Background

IG Farben used to be the largest company in Germany and the largest chemical company in the world. It was also one of the most innovative German companies in history, with three of its scientists winning Nobel prizes. IG Farben played an outsized role in the German innovation system, responsible for 5.9% of all patents by German inventors, up to 16.7% in chemistry. For comparison, IG Farben's share of German-invented German patents was three times that of AT&T/Bell among US-invented US patents (2%, see Watzinger and Schnitzer, 2022). IG Farben's fate has attracted considerable interest from historians (Haber, 1971; Hayes, 1987; Plumpe, 1990; Kreikamp, 1977; Stokes, 1988, 1994, 1995; Jeffreys, 2010) due to its industry dominance and controversial history. This section provides a brief overview of IG Farben's rise and fall, to contextualize the economic analysis of its breakup.

2.1 Making IG Farben

Figure 1: The Development of I.G. Farbenindustrie A.G.



Notes: Shows the historical time-line of IG Farben, from preceding cartels, 1925 merger and subsequent breakup using stock transfers. Source: Stokes (1988, p. 12). Does not include smaller subsidiaries as well as close cartels of IG Farben in the explosives industry.

In 1925, IG Farben was formed by merging several of the largest German chemical companies into a single stock company. Figure 1 presents IG Farben's timeline and eventual split. Before the merger, the firms were part of an organized cartel of the same name. Cartels were widespread throughout the German economy at the time; however, German laws stipulated that each member could quit unilaterally. These regulations created hold-up problems among the cartel members: If each member could leave and break the cartel, then forfeiting one's own sales division or name was inconceivable. To resolve these inefficiencies, cartel members merged, thereby relinquishing their outward profile to join the new *IG Farbenindustrie AG*. In addition to holdup problems (ter Meer, 1953, pp. 17–23), easier access to capital further incentivized the integration (Abelshauser, 2003, p. 228). Both factors are merger efficiencies in today's view.

IG Farben's internal organization was characterized both by specialization and redundancy. While a central administration took over important functions, production and research remained organized at a lower level (Haber, 1971, pp. 338–340), a practice called "centralized decentralization". For example, IG Farben maintained at least 25 research laboratories (Plumpe, 1990, p. 475) with wide geographical distribution across Germany (see Figure 2). Inventive activity occurred within in all major work units (Haber, 1971, p. 357; ter Meer, 1953, pp. 29–30) and many units maintained their own patent offices.[9] Nonetheless, IG Farben rationalized production and specialization increased (Haber, 1971, pp. 286–287). However, duplication remained, as "almost all of the central factories produced a broad range of basic chemicals, intermediates, and finished products" (Stokes, 1988, p. 18). Consequently, the IG Farben breakup would later create competition within technologies and product markets.

During the Second World War, IG Farben was instrumental to the German war effort and committed war crimes and crimes against humanity.[10] During its 20 year existence, IG Farben retained or acquired a dominant position in much of the German organics, plastics, and explosives industry. Further, IG Farben was directly or indirectly responsible for producing much of the synthetic fuel and rubber from German coal as import substitutes. As part of a broader autarky strategy, the company was vital for the start and continuation of the war. IG Farben also conducted extensive acquisitions in the German-occupied territories and was later accused of plundering. Like many German industries, IG Farben sourced forced and slave labor from concentration camps. The most infamous IG Farben investment was at Auschwitz, where IG Farben built – yet, never completed – one of its most advanced facilities. Furthermore, an IG Farben subsidiary supplied the Zyklon B pesticide used for murdering more than a million people at Auschwitz and other camps. IG Farben's actions before and during the war fueled the company's reputation as "Hell's cartel" (Jeffreys, 2010).[11]

2.2 Breaking IG Farben

IG Farben's importance to the German war machine and its crimes drove the Allied powers to confiscate IG's property in 1945, leaving the administration in the hand of the respective zonal government. Meanwhile, the heightening cold war tensions complicated the Allies' attempts to coordinate their occupation policy (Stokes, 1994, p. 71). Their subsequent actions differed greatly. While the Soviets quickly began dismantling their IG plants, each Western Ally grew more hesitant and "became increasingly protective of the interests of the former IG group in its zone" (Stokes, 1994, p. 71). Even the US administration, initially set on separating IG Farben into small units, relented to the new economic and political realities. The Western integration of the US, British, and French occupation zones into the bizone and, later, trizone unified the

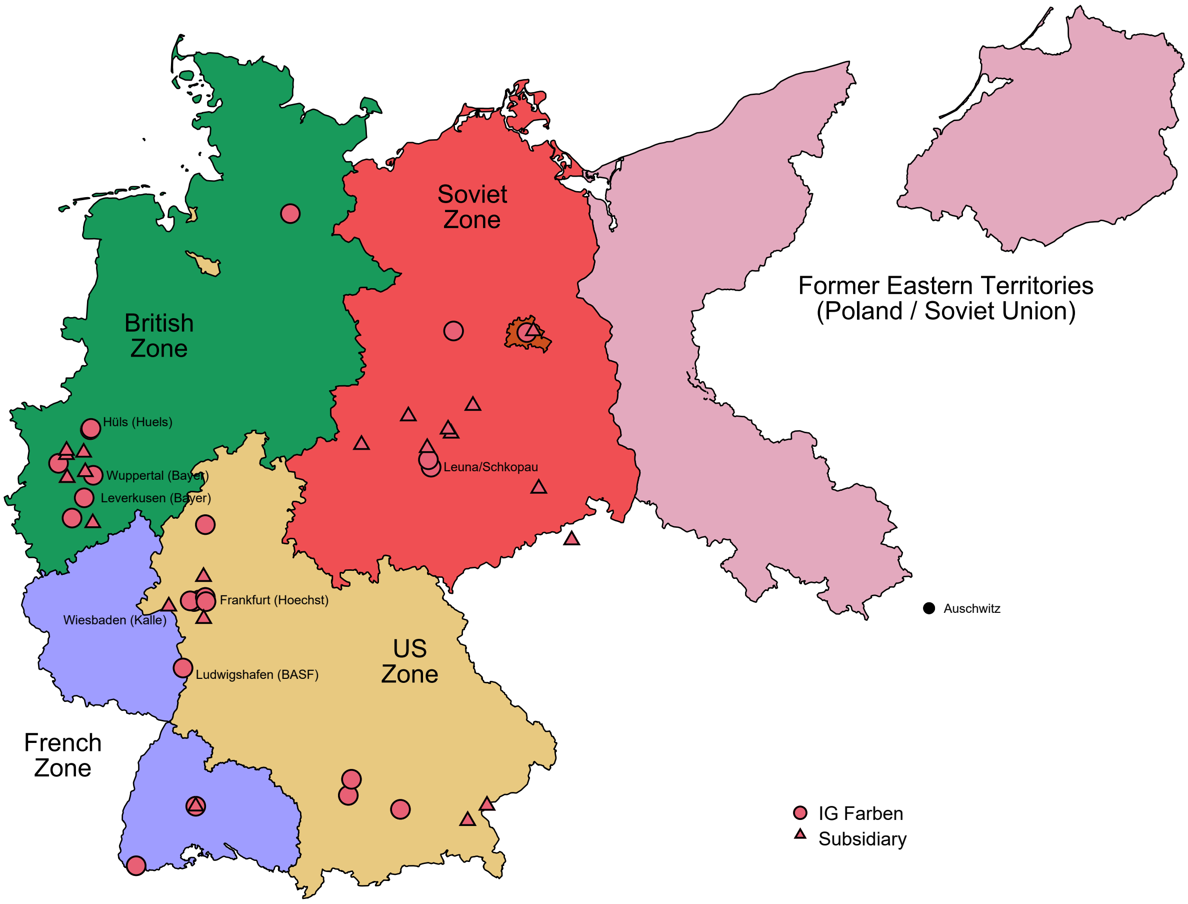
[9] In supervising its complex structure, IG Farben created multiple internal groups ("Betriebsgemeinschaften", Stokes, 1988, pp. 14–19). Control over production remained with the production groups. A total of five such groups encompassed 33 major production complexes, of which Table H-2 in the appendix lists the main ones. The groups specialized in certain areas of chemistry, such as Upper Rhine (Ludwigshafen, later BASF) in high-pressure chemistry, Lower Rhine (Leverkusen, later Bayer) in pharmaceuticals, or Berlin in photographic paper, film, and artificial silk. Working committees within the wider IG Farben administration attempted coordination between the groups.

[10] See Appendix H for a more thorough discussion of the historical context.

[11] For a discussion of the economic considerations of IG Farben's activities during the war, see Section H.

Allied administration of IG Farben. As a result, Stedman (1950, p. 442) calls the 1945 breakup "largely theoretical" and states that "[t]he individual units today are in closer collaboration than they were then". While this claim is certainly exaggerated, it demonstrates some US officials' disappointment with the state of German deconcentration. The breakup question was resolved in earnest only in the early 1950s.

Figure 2: Locations of IG Farben manufacturing and research



Notes: Shows IG Farben locations in Germany's 1936 territory, by postwar situation. BASF formed around the Ludwigshafen facilities in the French occupation zone (blue). Bayer formed around facilities in the British occupation zones. Hoechst formed around the facilities in the United States occupation zone (yellow). Some locations (Troisdorf, Marl-Hüls, Wiesbaden) formed smaller successors. The large facilities the Soviet zone (red) in Leuna, Schkopau and Wolfen were restructured as publicly owned enterprises (Volkseigener Betrieb, VEB). The former German areas in the East became Polish or Soviet Union territories after 1945 and did not contain major research-active IG Farben facilities. The IG facilities near Auschwitz, in occupied territories, received large investments during the war, yet never reached completion. Source: Max Planck Institute for Demographic Research: MPIDR Population History GIS Collection, own calculations.

IG Farben's breakup was not expected or planned before the war, and its structure was only determined during the occupation period. IG Farben officials saw the writing on the wall, but eventually, preparation for the Allied victory remained rudimentary (Stokes, 1988, pp. 32–33).[12] Stokes, writes:

[12]Some attempts were made, however. IG officials attempted to transfer ownership of foreign assets to avoid confiscation. Ideas such as a legal separation of war-related factories from civilian production were considered but dropped. In the end, these decisions would be taken by others.

> Although the final outcome of the breakup was not predictable in 1945, zonal policies helped prejudice its general contours. Practically speaking, the major Western successors of IG Farben were going to be the three large works units of the old firm, the central factories of which lay in different zones. (Stokes, 1994, p. 71)

With this, the eventual breakup largely followed IG Farben's internal structure. This, however, was not the only possible outcome. Initially, US officials considered an arrangement with much smaller units. This idea was initially implemented in the US zone, but by 1952, Hoechst had largely reassembled its structure. Another Allied proposal would have grouped activities related to synthetic fibers and artificial silk into one successor, which would have bundled the plants Dormagen (later Bayer), Bobingen (later Hoechst), and Rottweil (later independent). However, this proposal was abandoned mainly due to British political support for Bayer (Stokes, 1994, pp. 73–75).

In 1951, the Allies announced the final breakup structure, and the major successors were legally incorporated by 1952.[13] The breakup was executed via stock transfers. Each owner of IG Farbenindustrie AG shares received successor shares according to their initial capitalization. IG Farben patents were redistributed among the successors, primarily according to the location of invention and occasionally according to current use. However, all successors were granted non-exclusive royalty-free licenses.[14] In the years following the breakup, the successors thrived in separation. Although they began to acquire non-IG Farben competitors, especially in the early 1960s, the breakup structure was not majorly adjusted until 1970.

2.3 Historical context

IG Farben's breakup occurred during one of the most turbulent episodes of German history. Yet, the German economy and society were neither immediately nor fundamentally transformed. Historically, a core question is whether the end of the Second World War set off a complete renewal ("Hour Zero") or was rather characterized by societal and economic continuity. This question was the subject of intense debate in post-war German society. Both for society and for

[13]Between 1945 and the finalization of the breakup in 1952, IG Farben itself was in flux. Zonal structure divided effective control among the four Allied Powers in 1945. Then, the consolidation of the Western occupation zones consolidated the administration into the Western and Eastern zone by 1948. In August 1950, the Western Allies created the legal basis for separating IG Farben. The incorporation of the main successors (Hoechst on December 7, 1951; Bayer on December 19, 1951; BASF on January 30, 1952) concluded the most important part of the breakup.

[14]For example, BASF received over 2200 patents invented in its own units, compared to 26 patents invented in other units, 76 jointly invented with another unit, and roughly 30 patents jointly invented with third parties. See HHStA/2092/14781, 17305, 17306. For patent licenses, see regulation No 2 under Law 35 of the Allies High Commission (AHK/98/2010-2012). Free licenses were available to fully owned IG Farben subsidiaries, discounted licenses to majority-owned ones.

the economy, historians today emphasize continuity and reject notions of a radical divergence (e.g. Morsey, 2010). Overall, the German economy recovered quickly and returned to pre-war export levels by 1950.

Nonetheless, several historical factors were crucial for German industrial development. The war left German cities with varying degrees of damage. After the liberation by the Allied Powers, Germany was occupied and divided into occupation zones. With the occupation came industrial controls, including the dismantlement of industrial capacity to reduce the German war potential or to serve as reparations. Eventually, differing occupation policies would lead to economic and political division between East and West Germany.

In most cases, the aforementioned historical factors affected all sectors of German industry. However, insofar as effects are differential, they present limitations to this paper's generalizability. For many aspects, it is possible to introduce control variables for statistical robustness checks. For others, detailed discussions of the historical circumstance in Appendix H guide an appraisal of the limitations.

3 Data

Patents Patent data serves as a proxy for innovation, based on the idea that patents are most suitable to protect chemical and pharmaceutical innovations and provide valid measures of innovative activities in these fields (e.g. Cohen, Nelson, and Walsh, 2000; Moser, 2012).[15] I digitize German patent grant documents ranging from the 1920s to the 1960s to obtain information on technology class and application year. This period starts five years before the IG Farben merger and ends ten years after the breakup, following Stokes (1994). The sample restriction also reflects data availability.[16] This data construction complements data provided by the German patent office and fills in unavailable or unreliable information. Appendix A discusses the data construction process in detail and assesses various quality aspects. Of special note, the German patent office ceased operations for most of 1945 and all of 1946 and 1947. I always exclude these years. I further exclude war-time applications in most analyses due to the circumstance of their application, but also because the patent office only processed them in the 1950s. Applicants will selectively pursue prosecution of patents still relevant 5-10 years after the original application.

[15]During the time of interest, the German patent law did not allow product patents in pharmaceuticals and chemistry. However, processes were patentable. These were effective in deterring entry, as a competitor producing the same product would have to prove that they employed a different process (Uhrich, 2010).

[16]After the sample period, the German technology classification and publication regime changed. As a result, many grant documents are unavailable for digitization, and the German technology classes are no longer reported on others. During the sample period studied here, patent grants, as observed in the data, track information from official statistics well, but this correlation breaks down during the mid-1960s.

Technology classes For ease of access, patent offices have long classified patents by technology classes. While these are not congruent to individual markets or products, technological experts considered them relevant at the time. During the sample period, the German classification system contained 89 technology areas, which were themselves split into about 560 technology classes and over 20,000 technology groups (in 1949). However, whereas technology areas and classes are largely consistent over time and can be extracted from patent documents with high precision, groups undergo rapid change as technology evolves. Consequently, the analysis in this paper focuses on technology classes. Of those, only a subset relates to chemistry. Following Baten, Bianchi, and Moser (2017), I identify all classes related to chemistry based on descriptions of the technological content. In total, 135 relevant technology classes, belonging to 34 areas, remain and form the basis for this study's analysis.[17]

Patent quality As patent quality is heterogeneous, adjustments are advisable, most commonly via weighting with patent citation counts (Harhoff et al., 1999). However, patent citation information is unavailable in the historical German patent data. I adopt an alternative quality measure based on text similarity scores between patents (Kelly et al., 2021).[18] Patents similar to future patents are called influential, while patents similar to past patents are called derivative. Kelly et al. define text-based patent quality as the ratio of future and past similarity and show that text-based and citation-based quality correlate well. I adopt Kelly et al.'s methodology for the German context.[19] I normalize the patent-level quality measures to mean three and standard deviation one so that quality-weighted patent counts are of comparable scale but also non-negative. To validate the quality measures, I collect two alternative proxies for quality. First, I digitize information on patent lapses from a publication series ("Patentblatt") of the German Patent Office and calculate the effective patent lifetime. Patent lifetime and quality scores correlate well. Second, I digitize a list of important chemical patents as identified by a contemporaneous publication series. Quality also correlates with being noted as important. I discuss details in Appendix A.5.

Inventors Inventor information is used to understand IG Farben's pre-breakup structure and follow inventor careers, among others. I extract inventor information from patents and

[17]For comparison, the U.S. Patent Classification System has approximately 475 classes and 165,000 subclasses. Chemistry is a wide field and includes applications in fields such as pharmaceuticals, agriculture, photography, but also (chemical) engineering, material science, etc. Appendix I lists all technology classes included in the analysis. Results are robust to alternative choices, see Table C-9.

[18]A limitation of using text-based analysis with chemical patents is the presence of formulas. In a random sample of 100 patents in the relevant technologies, about 10% contained a formula. However, as chemical patents primarily protected processes during the period of interest, patents tend to be very verbal and give detailed synthesis examples.

[19]Unlike the US context, institutional factors cause the total count of German patents to vary widely over time. To account for this, I use the average future/past similarity instead of the sum of future/past similarity scores. I further employ a modern text similarity algorithm that focuses not on word counts but on the text's overall structure (Doc2Vec, see Le and Mikolov, 2014). Appendix A discusses details.

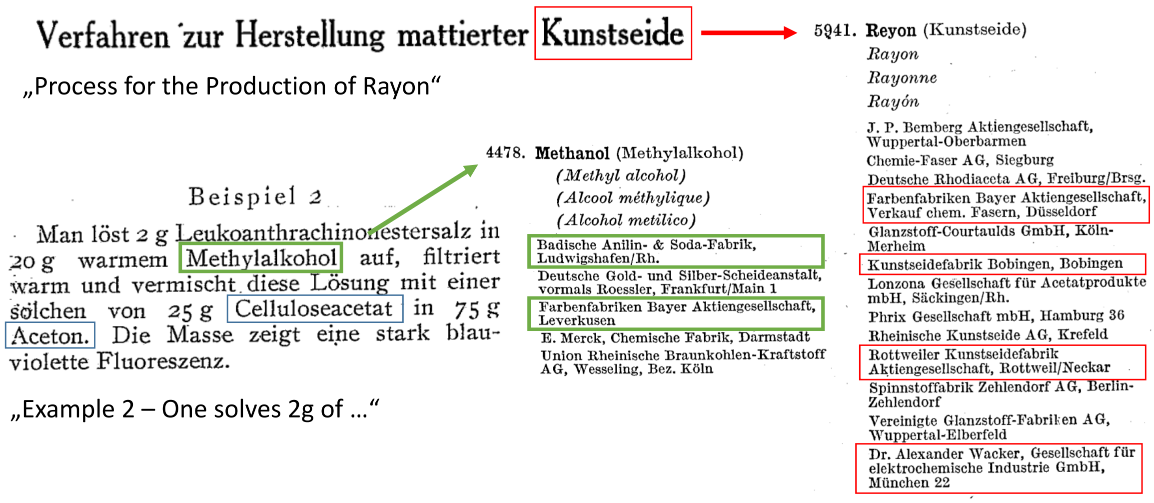
complement them with entries from the membership lists of the German Chemical Society (1950 and 1953) to track non-patenting inventors. Patents consistently list inventors from 1937 onward, but inventors have already been available for almost all IG Farben patents since the 1920s, similar to other large firms. I geolocate inventor locations and disambiguate patent inventors, as well as chemist addresses, into inventor profiles. The disambiguation uses information on names, titles, locations, and the year and text content of patents but does not take the applicant firm into account. With this, it is possible to analyze the role of inventor mobility in the effects of the breakup.

Product catalogs Historically, product catalogs provided information to industrial purchasers about a large number of established chemical products and the identity of suppliers. With the catalogs, I can determine whether a product was offered by one or multiple IG Farben successors after the breakup and how many other firms were active in the market. In the analysis of products, I focus on the product catalog of mid-1952, which describes the situation immediately after the breakup was finalized. In the descriptive analysis, I also use product catalogs covering late 1939 – the last catalog published before the war – and 1961. The 1952 catalogue contains 7619 entries. Of these, about 3,400 are brands (which I drop), and about 900 are alias references to other products without supplier lists. Other entries contain multiple product names. Using aliases derived from the 1939, 1952, and 1961 product catalogs and additional methods, I group catalog entries into *products*. The final list comprises 3,139 products, which includes chemical substances (N=2,694) and product categories (e.g., industrial cleaners or paints, N=445). In the main analysis, I include both, but the results are qualitatively similar when focusing on homogeneous products only. For additional details, see Appendix B.

Price lists For a subset of the product data, supplementary data on product prices is available. Between late 1948 and the mid-1950s, German industry journals published monthly prices on a rolling basis, likely because prices were adjusting after price controls were discontinued and companies valued price overviews. As a result, on average, 470 price points are available each month. Prices are listed in German Marks, typically per kg of product. At least one price point is available for a subset of nearly 1,800 products, which are almost exclusively substances rather than product categories. For a single product, prices can be differentiated by quality grade, in which cases there can be more than one time series of prices. For the analysis of the breakup, price information before and after the breakup is required. With these criteria, 393 products with 515 price time series remain. I obtain additional data about chemical structure, tariffs, cartels, and others for this subset of products. For additional details, see Appendix B.

Linking patents and products I use patent full texts to link patents and products. As illustrated in Figure 3, the name of a product can occur in the title, text description, or exemplary process descriptions, which are often included in patents. Such in-text mentions capture the relevancy

Figure 3: Linking patents and products via full-text analysis



Notes: Displays an example for the procedure of linking patents and products. Patent DE636840A's title indicates a production process for rayon (in red, top and right, offered by four firms related to IG Farben), whereas examples in the text body indicate that among others, methyl alcohol is an input (in green, bottom and left, offered by two firms related to IG Farben).

of a product for a particular patent (technology) but can refer to an input, output, or another functional role. To minimize the extent of spurious matches, the text matching focuses on whole words and, if multiple products fit a particular text segment, prefers mentions that cover longer text sequences.[20] The resulting data is a count of in-text mentions N_{jk} of product k in patent j. Based on the product catalogs, the number of IG Farben suppliers can then be identified for a given product, and the data can be aggregated either on the technology level or the product level. The aggregation is further discussed in Section 6.7.

4 Product-level and technology-level competition

4.1 Product-level competition and price effects

A large number of products was exposed to additional competition as a result of the IG Farben breakup. Table 1 starts from the 1952 product catalog and shows the share of products with multiple, one, or no IG Farben (successors) being active.[21] Around 40.6% of all products were offered by IG Farben, and of those, 34.6% were offered by multiple successors - indicating that

[20]The main challenge with this approach lies in the computational requirements of looking up thousands of product names in more than two million patents rather than the text-matching algorithm itself.

[21]By 1952, some adjustment of the supplier status would already have occurred, which is a limitation of this analysis. Unfortunately, all pre-breakup catalogs do not allow disentangling which (eventual) IG Farben successor produced a given product.

product market competition was induced by the breakup. The lower half of Table 1 focuses on a balanced panel of products also listed in 1939 and 1961. Before the war, the presence of multiple IG Farben-associated companies (separately named subsidiaries or joint ventures) was much more rare. Additionally, while there is some exit and entry, the competition between IG Farben successors remained in place also ten years after the breakup. At the same time, IG Farben (successors) were far from the only chemical companies active in the German product market. Products with at least one IG Farben supplier in 1952 were on average offered by 8.2 firms, among them 1.6 IG Farben successors. When excluding product categories, i.e., focusing on chemicals, the catalog lists 3.2 suppliers, of them 1.4 IG Farben successors. Non-IG Farben products were on average offered by 3.3 firms (2.1 among chemicals).[22]

Table 1: Exposure to post-breakup competition; conditional on 1952 IG Farben status

Products listed in 1952

	IG Farben Products (N=1296)			Other Products (N=1896)		
	No IG	One IG	2+ IG	No IG	One IG	2+ IG
1952	0%	65%	35%	100%	0%	0%

Products listed in 1939, 1952, and 1961

	IG Farben Products (N=346)			Other Products (N=534)		
	No IG	One IG	2+ IG	No IG	One IG	2+ IG
1939	32%	57%	12%	85%	14%	1%
1952	0%	56%	44%	100%	0%	0%
1961	29%	33%	38%	93%	6%	1%

Notes: Describes the number of IG Farben successors, split by whether products were offered by IG Farben-connected companies in 1952. The upper half of the table focuses on all 1952 products (excluding brands), whereas the lower half focuses on a balanced table of products offered in 1939, 1952, and 1961. Rows tabulate the status in 1952 (upper half) and 1939, 1952 and 1961 (lower half). The first set of columns focuses on products offered by IG Farben in 1952 and shows shares by current supplier status. The second set of columns looks at products only offered by other companies in 1952, again showing shares. For a table excluding product categories, see Table B-1 in the appendix.

For a subset of products, information on prices and chemical characteristics of products is available. The subsequent analyses focuses on a dataset starting with the 1952 product catalog, matched to the price lists. The dataset focuses on entries with price information both before and after the breakup. As discussed in Section 3, for each product catalog entry, there can be multiple quality grades (e.g., by purity), so that the data comprises 393 products with 515 price time series.

[22]For a table corresponding to Table 1 but focusing on chemical substances, see Table B-1 in the appendix. Among chemical substances, 35.7% are offered by any IG Farben successor, and of those, 25.7% were offered by multiple successors.

Overall, IG Farben products are more likely within basic chemicals, whereas other chemical companies in Germany tended to specialize in more niche or specialty chemicals. However, a substantial overlap exists. Table 2 shows a balancing test between the different groups of IG Farben exposure. As expected, the groups are unbalanced. Prices per kg for IG products were lower,[23] their chemical weight – a first indication of complexity[24] – is smaller and the number of competitors is larger compared to non-IG products. In terms of tariffs, pre-war tariffs on IG products were higher than on non-IG products, but the post-war difference is negligible.

Table 2: Price analysis: Descriptive statistics

Comparing products: Multiple vs one vs zero IG Farben successors							
	2+ IG Farben	1 IG Farben	0 IG Farben	Difference (SE) 2+ vs 1		Difference (SE) 2+ vs 0	
Price (per kg, log)	4.98	5.77	6.34	0.79	(0.20)	1.37	(0.20)
Quality grades	2.05	1.56	1.45	−0.49	(0.13)	−0.60	(0.10)
Molar mass (g/mol)	99.40	140.50	192.07	41.10	(9.84)	92.67	(13.25)
- Heaviest element	27.60	36.45	48.69	8.85	(3.66)	21.09	(4.84)
- Remaining mass	58.78	85.95	115.04	27.17	(8.87)	56.26	(12.62)
Anorganic	0.41	0.41	0.44	0.01	(0.06)	0.04	(0.05)
Organic	0.36	0.37	0.44	0.01	(0.06)	0.09	(0.05)
Pharma	0.13	0.16	0.08	0.03	(0.05)	−0.04	(0.03)
Plastics	0.11	0.03	0.01	−0.08	(0.03)	−0.10	(0.02)
Metal	0.00	0.03	0.02	0.03	(0.02)	0.02	(0.01)
Suppliers (1939)	8.01	5.00	4.06	−3.01	(0.64)	−3.95	(0.57)
- Non-IG	6.06	4.05	3.79	−2.00	(0.64)	−2.27	(0.56)
Suppliers (1952)	7.76	4.17	2.81	−3.60	(0.53)	−4.95	(0.41)
- Non-IG	4.11	3.17	2.78	−0.94	(0.41)	−1.33	(0.32)
N	118	126	271				

Notes: Shows observable characteristics of products with multiple, one, or without IG Farben successor as supplier in 1952 (columns 2-4) and differences among products with multiple vs. one (columns 5-6) or multiple vs. zero successors (column 7-8). Sample: 1952 product catalog matched with prices, pre-breakup data only. Appendix B explains the data in details.

[23] While IG prices are on average lower, it is important to note that absolute prices crucially depend on the nature of a product. Some products, for example radioactive luminescent colors, are only used and sold in small amounts and thus have exceedingly high per-kg prices. Winsorization is used to contain the effect of such outliers in the balancing tables whereas in regressions, product fixed effects suffice.

[24] As an indication of complexity which is available for a broad set of chemicals, I focus on the molar mass. Molar mass is the weight of a substance sample divided by the number of contained molecules, measured in weight per mole (mol, a standard unit for the number of particles). For the purposes of this analysis, it is only relevant that the molar mass rises with the number and size of atoms contained in a compound. Molecules are heavier if they are more complex (e.g. large organic compounds such as Chlorophyll) or if they contain with heavy atoms (e.g. lead salts). To capture the latter explanation, the atom with the largest atomic mass is identified from the chemical formula. The molar mass reduced by all occurrences of this atom is listed as ‘remaining mass’. Overall, substances sold by IG Farben are lighter and with lighter heaviest atom. Note that this is unlikely to be driven by a distinction in organic/inorganic chemistry, where share differences are not large enough to explain the difference.

Table 3: DiD estimates for price effects

log(price)	DiD			PS-Match+DiD			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
One IG in 1952 × Post	0.069**	0.079***	0.083***				
	(0.030)	(0.029)	(0.032)				
Two+ IG in 1952 × Post	−0.074***	−0.059**	−0.066***	−0.093***	−0.079**	−0.081**	−0.083**
	(0.025)	(0.024)	(0.025)	(0.029)	(0.038)	(0.038)	(0.041)
Product, Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls × Month FE			Yes				Yes
Pre-treatment price				Yes	Yes	Yes	Yes
Chemical properties					Yes	Yes	Yes
Competitor count						Yes	Yes
Products (clusters)	393	393	334	278	212	209	180
Price time series	515	515	445	358	263	262	230
Adj. R-Square	0.991	0.992	0.992	0.982	0.984	0.986	0.986
Observations	9027	8854	7640	6341	4636	4586	4036

Notes: Shows difference in difference estimates for a assumed event time in 1950Q3, allowing for potential short-run effects of the breakup announcement. Unit fixed effects at the product grade level are present in all regressions. Time fixed effects are at the month level (prices). Columns 1-3 show effects based on the 1952 structure of the IG Farben successors, and columns 4-7 use propensity score matching to adjust for varying pre-treatment differences. Column 2 and 3 exclude data of 1949Q1 and earlier due to large price changes observed in this period. The baseline is always the group of products without IG Farben involvement. Controls include the chemical type, presence of cartels, and tariff changes following the 1951 tariff adjustment. Chemical types are organic, inorganic, metals, pharmaceuticals and plastics. Products with involvement of at least one sales cartel in 1939 are considered as cartelized ("Cartel"). Changes between the previous special tariff and the subsequent ad valorem tariff after the 1951 tariff adjustment are the Δ Tariff control variable. The difference is winsorized at the 1% and 99% level. Both tariffs are calculated as percentages and Δ Tariff is the difference. When information about quality grades (e.g. 'pure') is available, multiple time series per product exist, indicated by the number of price time series. Standard errors clustered on the product level in parentheses.

All in all, prices for products with ex-post IG Farben competition fall relative to prices of other products. Table 3 reports regression coefficients on the price data. Columns 1-3 show price tendencies in a simple DiD analysis, comparing prices of products with multiple (one) IG Farben successors as suppliers to those without any IG Farben-related supplier. Here, I observe that prices with post-breakup competition are moderately, 6-7%, smaller than non-IG Farben products, whereas prices of products with one IG Farben successor even increase. Columns 4-7 use propensity score matching on a series of properties to adjust for the systematic differences in the composition of products observed earlier. Here, the regressions only compare products with multiple IG Farben successors to such without. Effects are of marginally magnitude, indicating price decreases of 8-9%. For plots of the raw price data, see Appendix B.

4.2 Technology-level competition

I characterize the exposure to the IG Farben breakup with measures of technology-level concentration changes, which equivalently measures the extent to which the breakup created multiple IG Farben successors with capabilities in a technology. In general, technology-level concentration does not equate to traditional measures of competition in product markets, and such extrapolations should remain cautious. Technologies as defined by patent classifications likely encompass many products; thus, changes in technology concentration likely hide substantial variance in product-level change. In principle, it is even possible for a breakup to yield significant technology-level changes without product-level changes if the breakup happens between products, as in corporate de-mergers. In the IG Farben case, this is unlikely as (based on historical product catalogs) the breakup created substantial product-level competition as well. Similarly, a product can be subject to inputs from several technologies. Despite these caveats, the technological dimension itself is important (Bloom, Schankerman, and Van Reenen, 2013) and competition for technological capabilities is a precursor to competition in future product markets. In subsequent analyses, I use product-level data to distinguish between product-level and technology-level competition.

I measure breakup exposure, the concentration change caused by the IG Farben breakup, as $\Delta\text{HHI} = \text{HHI}^{IG} - \text{HHI}^{\overline{IG}}$. This equation captures the hypothetical difference in concentration either with IG Farben as one entity (HHI^{IG}) or when broken up into successors according to the eventual assignment rules ($\text{HHI}^{\overline{IG}}$). So defined, the concentration change ΔHHI is non-negative. The intuition for ΔHHI is that each of the successor companies was assigned one or more R&D units that were previously under the IG Farben umbrella. R&D units typically operated in several technology fields, with considerable overlap between them. As such, ΔHHI is high in a field if multiple successor companies had considerable technological capability assigned to them. For example, consider a technology field with 500 patents, of which IG Farben developed 100, and all other patents were developed by separate firms. Pre-breakup HHI^{IG} would be slightly above 400. If the IG Farben patents were produced by two successors with 50 patents each, then $\text{HHI}^{\overline{IG}}$ would be slightly above 200, and ΔHHI would stand at 200, not too different from technology 12K (Table 4). Figure 4b provides an intuition across the range of technologies by plotting the technology-level share of patents by the four largest IG Farben successors. Everything else being equal, ΔHHI increases when technological capability is more equally distributed among IG Farben successors, or the total IG Farben share is higher. Below, I discuss a measure which isolates the former component.

The empirical measurement of ΔHHI needs to consider the historical circumstances. Due to war-related changes and potential endogenous adjustments of the IG Farben's technology portfolio in the early post-war years, I measure ΔHHI in the pre-war period. However, $\text{HHI}^{\overline{IG}}$

– the HHI of IG Farben in it's broken-up state – is unobserved during IG Farben's lifespan as a unified corporation because the bulk of IG Farben-related patents was filed as applicant "IG Farben". As the breakup had strong geographic components, I can reconstruct its structure based on R&D locations revealed through information about the patents' inventors. With the geographic dispersion of research facilities across Germany, the inventors' locations reveal an association with the eventual successors. Closely following the post-war patent reassignment (see Section 2.2), I assign inventor locations to the nearest research facility or, alternatively, according to the inventors' pre-merger or post-war employer. This process is successful for up to 90% of IG Farben patents.[25] I discuss details of the reassignment process in Appendix A.7. As an example, Figure 4a presents the results for BASF.

For the main results, I focus on ΔHHI as measured in the pre-war period (e.g., 1925-1939). However, the results are robust to the equivalent measure from the post-war, pre-breakup period (1948-1951). As post-war patents were primarily granted after the breakup, I can observe the post-breakup structure directly via applicant information. $\text{HHI}^{\overline{IG}}$ is observed, and HHI^{IG} can be recovered by considering all successors as one block, thereby excluding noise from the reassignment rules. For the main analysis, however, a focus on pre-war patents is preferable as the resulting exposure measures are unaffected by the effects of the war and potential anticipation.

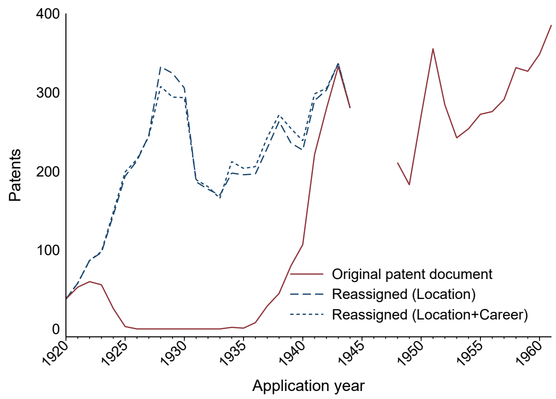
In Table 4, I provide concentration (change) measures for selected technology classes in which IG Farben was strongly engaged. In technology classes traditionally associated with the dye manufacturing, IG Farben's traditional business, the breakup implied substantial changes exceeding 1000 points. However, there is substantial variance. For example, exposure is relatively weaker in ammonium and pharmaceuticals, despite the intensive engagement of plants such as those constituting the successors BASF and Bayer, respectively. To characterize the overall concentration change, I divide classes into high and low breakup exposure, splitting at the 75th percentile (cutoff 187).[26] In the top 25% of classes, ΔHHI is very large, on average almost 1,200. In contrast, in the remainder of chemistry (and outside of chemistry), the breakup had almost no effect on technology-level concentration. In 32 classes, ΔHHI is zero as none or only one IG Farben successor is active in the technology. Concentration changes measured based on the post-war pre-breakup period are generally smaller, although still substantial.

[25] The 10% unassigned patents cannot be considered for calculations of ΔHHI. I assign them to the IG Farben successors while preserving shares. For example, if one patent was assigned to BASF and Bayer each, but one patent remained unassigned, I proceed as if 1.5 patents were assigned to BASF and Bayer. I apply the same procedure towards patents by East German IG Farben successors as they quickly become irrelevant for West German technological development.

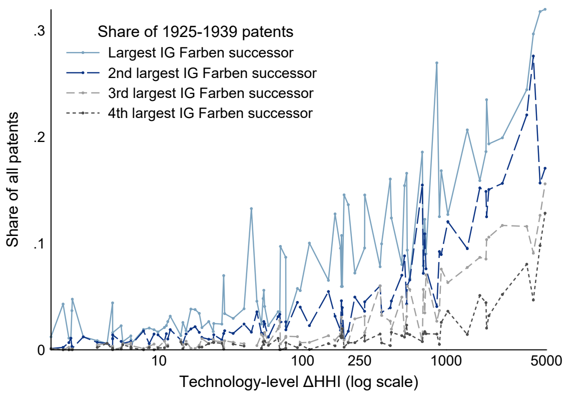
[26] For reference, a merger with an effect of $\Delta\text{HHI} > 100$ or > 200, depending on absolute HHI, would be above the FTC screening thresholds for product markets. However, direct comparisons between concentration in antitrust markets and technologies come with caveats, as discussed at the beginning of this section.

Figure 4: Firm contributions to ΔHHI

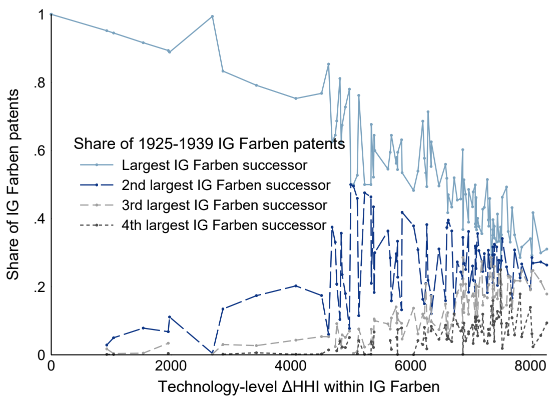
(a) Patents of BASF, assigned by inventor locations



(b) Overall ΔHHI



(c) Within-IG Farben ΔHHI



Notes: Top: Original patents and reassignment for BASF. Subsidiaries aside, IG Farben's Frankfurt headquarter is the applicant listed on all IG Farben patents. However, unlike most companies at the time, almost all patents list inventors. Due to the geographic spread of IG Farben's research facilities, inventor locations allow the reassignment to eventual successors. Only in some cases are the inventor careers from deduplicated patent applications more informative. Here, inventors are reassigned to their post-war place of employment. The graph shows the yearly number of granted patent applications for the successor BASF. Numbers are as listed on the original patent documents (solid red line), as reassigned to eventual successors using location information (dashed blue line), and as reassigned to eventual successors using location information and inventor name disambiguation (solid blue line). For the full set of successors, see Figure A-8. **Bottom:** Patents in chemical technologies, 1925-1939. IG Farben patents were reassigned to successors. **Bottom left:** Change in technology-level concentration for technologies with ΔHHI $\geq$ 1, log-scale. The y-axis shows the share among *all* patents of the four largest IG Farben successors. **Bottom right:** Change in within-IG Farben concentration for technologies with IG Farben patents. The y-axis shows the share among *IG Farben* patents of the four largest IG Farben successors.

Finally, I calculate alternative measurements of ΔHHI that remove the effect of the amount of IG Farben investment and only focus on the distribution of investment across successors or occupation zones. The standard ΔHHI introduced above describes concentration changes within technology classes and relates to the previous literature. The change in HHI provides an intuitive description of the concentration change caused by the IG Farben breakup. However, HHI depends on the share of IG Farben-related patents in each technology class, which may be endogenous to future technological potential. A set of alternative measures removes this dependence by considering only IG Farben-related patents. Starting from this set, alternative

Table 4: ΔHHI implied by the breakup

Selected technology classes	Patents 1925-1939					48-52
	Count	IG %	HHI^{IG}	$\text{HHI}^{\overline{IG}}$	ΔHHI	ΔHHI
8M: Coloring	643	57.23	3412	951	2461	1752
12G: Processes (general)	400	26.25	739	331	408	174
12K: Ammonium, Cyanides	484	16.84	397	213	184	263
22E: Indigo-based dyes	377	77.72	6114	1610	4504	2706
29B: Chemical fibers	601	29.12	911	219	693	159
30H: Drug development	1050	15.05	262	111	151	70
39C: Synthetic plastics	325	52.31	2806	894	1911	783
45L: Pesticides	700	31.57	1077	368	709	245
Means for ΔHHI > p75 (N=33)	732	37.36	1846	620	1226	649
Means for ΔHHI ≤ p75 (N=102)	680	4.58	415	391	24	43
Means overall	693	12.59	765	447	317	192

Notes: Shows the concentration change implied by the IG Farben breakup for selected technology classes and by breakup exposure. The columns show the count of granted patents, the share of patents by IG Farben or subsidiaries (IG %), the Herfindahl-Hirschman index considering all as one block (HHI^{IG}) and split up according to the eventual successors ($\text{HHI}^{\overline{IG}}$) as well as the difference, ΔHHI. The first columns consider patents filed between 1925 and 1939, and the last column for 1948-1952. Patent counts are rounded from fractional counts. Statistics are calculated by technology class, means across exposed/comparison technology classes in the last two rows.

HHI can be computed, either by analyzing the breakup of IG Farben across successors or by exclusively analyzing geographical variation across occupation zones. To do so, I restrict attention to IG Farben-related patents. Consequently, $\text{HHI}^{IG} = 10000$ for all technology classes. $\text{HHI}^{\overline{IG}}$ either follows the structure of the eventual successors, determined as outlined above, leading to $\Delta\text{HHI}_{\text{Within}}$. Figure 4c depicts the share of the largest four IG Farben successors of the IG Farben portfolio plotted against $\Delta\text{HHI}_{\text{Within}}$. Alternatively, $\text{HHI}^{\overline{IG}}$ follows only the geographical distribution of IG Farben across the occupation zones. This this case, instead of successor shares, shares in the British, French, and US occupation zones form the basis of $\text{HHI}^{\overline{IG}}$.[27] This removes variation introduced from subsidiary structures and leads to $\Delta\text{HHI}_{\text{Occ}}$.

5 Empirical Strategy

My analysis is based on a difference in differences approach, comparing technologies with high exposure D_i to the IG Farben breakup to technologies with low or without exposure:

$$log(Y_{it}) = \alpha_i + \beta_t D_i + \gamma_t + \delta X_{it} + \epsilon_{it} \tag{1}$$

[27] As the IG Farben successors lose access to the Eastern zone, I exclude the small share of patents invented there.

The regressions include technology class fixed effects α_i, time fixed effects γ_t, as well as additional controls X_{it}. Exposure to the IG Farben shock D_i is a continuous variable measuring the concentration change caused by the IG Farben breakup. The primary outcome variable is innovation, operationalized as quality-weighted patent counts, with quality scores derived from patent texts. The units of observation are the technology class by application year.

For display purposes in tables, I group the yearly coefficients as in equation 2.

$$log(Y_{it}) = \alpha_i + \beta_{1948-1951} D_i + \beta_{1952-1961} D_i + \gamma_t + \delta X_{it} + \epsilon_{it} \tag{2}$$

One long pre-period covers the time before the war, when IG Farben was one company. I normalize the coefficient $\beta_{1925-1939}$ to zero to provide a baseline for the long-run, pre-war patenting level. The post-war, pre-breakup period is grouped into $\beta_{1948-1951}$. This period informs about new post-war levels. Finally, in early 1952, most successors had incorporated and the breakup had taken effect. The post-period is covered by the coefficient $\beta_{1952-1961}$ continues until 1961, following Stokes (1994). For this analysis, the main interest is on the difference between the two post-war coefficients, $\beta_{1952-1961} - \beta_{1948-1951}$.

As discussed in Section 4.2 in detail, I characterize the breakup exposure D_i using the technology-level concentration change induced by the IG Farben breakup (Nocke and Whinston, 2022). D_i equivalently measures the extent to which the breakup created multiple IG Farben successors with capabilities in a technology. Using the Herfindahl-Hirschman index (HHI)[28] as the measure of concentration, I operationalize breakup exposure as the difference between HHI^{IG} of IG Farben as a single entity and $\text{HHI}^{\overline{IG}}$ of IG Farben divided into successors according to the eventual breakup structure, so that $D_i := \Delta\text{HHI} = \text{HHI}^{IG} - \text{HHI}^{\overline{IG}}$. In the main analysis, ΔHHI follows the literature by calculating HHI from shares of IG Farben successors towards the overall set of patents in a technology class. However, the class-level ΔHHI combines exposure to the breakup through the intensity of IG Farben investment in a particular technology class as well as the distribution of investment among successors within the class. While this represents the economically relevant measure, focusing on the specific breakup rule and its geography is advantageous for identification purposes. Reassuringly, the results are robust to measures solely focusing on the breakup within the set of IG Farben patents, thereby isolating variation introduced by the breakup across occupation zones.

[28]Measures such as markups would also be desirable to characterize competition. Yet, the financial data of German firms are only available for a set of large, stock-listed companies and are limited to observations either before the war or after the breakup. The change in CR4 is also not helpful in characterizing the breakup as often the largest applicant (IG Farben) is replaced with three applicants (the successors), which are still the largest ones. The CR4 change is then entirely determined by the share of the two applicants shifted out of the top 4, which is unrelated to the breakup.

Identification assumptions For causal inference, I rely on two assumptions. First, I assume that without the breakup, classes with exposure $D_i = d$ would have developed as classes with exposure $D_i = 0$. This assumption is sufficient to identify level effects, specifically $ATT(d|d)$. Whenever ATEs or average causal responses are interpreted, a stronger version of this assumption is required (Callaway, Goodman-Bacon, and Sant'Anna, 2021). Second, I assume that the IG Farben shock can be separated from other contemporary changes, i.e., that exposure to the IG Farben breakup is independent of potentially confounding shocks.

The first assumption - parallel trends - stems from the historical literature, which suggests that the IG Farben breakup was a previously unanticipated event. Investments in technology and production capacity were long-term and did not account for the subsequent breakup as it was unforeseeable. This argument motivates a comparison between technology classes affected by the shock and those affected only slightly or not at all. While the variation of IG Farben investments across technology classes is not random, this variation is unrelated to the eventual breakup.

However, even if the breakup was unpredictable, IG Farben might still have invested in particularly promising technologies and markets. Breakup exposure ΔHHI is partially driven by the overall amount of IG Farben investment in a technology, which threatens the parallel trends assumption. I relax this assumption by focusing on the breakup structure across successors, particularly across geography. The breakup structure is predominantly determined by the geographic structure of the Allied occupation zones. Firstly, research and production were not randomly distributed across IG Farben facilities. However, the distribution is chosen independently from the Western occupation zones' geography, which historically strongly impacted the breakup structure. Without the zones' impact, alternative ideas such as a breakup into even smaller units would have been fathomable. On the other hand, IG Farben's re-organization into a unified structure could also have occurred. Further, different zonal structures could have yielded different outcomes. For example, had France not insisted on receiving its own area of influence, the successor BASF could have been part of the US zone, thereby changing the initial structure of breakup considerations. Furthermore, a breakup along production lines instead of geography was also a theoretical possibility. These factors facilitate a weaker version of the first identification assumption: technology classes with different research investment distributions across successors or occupation zones would have, absent the shock, developed in parallel.

The second assumption is that the IG Farben shock can be separated from other contemporary changes. I test the influence of many parallel events and test robustness by including control variables for war destruction, dismantlement, the German separation, among others. The timing of the IG Farben breakup further allows for a discussion of the influence of historical factors. I provide a detailed historical appraisal of these various factors in Appendix H. I also show robustness to historical factors in a firm-level specification, in which control variables are constructed differently. With respect to timing, a relevant concern is that the breakup could have resolved uncertainty about the future of the German chemical industry. As a result, firms may have released previously generated ideas, also for example from inventions that were under secrecy during the war time. As I discuss in Section 6.8, then the increase in innovation, particularly in the first years after 1951, should been driven by inventors that were already active in the pre-war period. This, however, was not the case. Further, although there is some evidence for a short-run change in the propensity to patent (Section 6.4) there is no post-breakup spike in patenting by the IG Farben successors compared to other firms (see Appendix F).

6 Effects of the Breakup on Innovation

The main outcome variables relate to the patenting activity in a technology class, either overall or restricted to non-IG Farben firms. While the theoretical literature, as well as antitrust litigation, focuses primarily on direct effects on the merging parties, an aggregate view is crucial for an economic analysis of the breakup.

I first present descriptive statistics of the estimation sample. This sample is a technology-year panel of chemical technology classes. To present summary statistics, I group technology classes into those with high and low breakup exposure, split at the 75th exposure percentile. The low-exposure group also comprises 32 classes in which ΔHHI is zero.[29] The technology classes are comparable before the war. Table 5 demonstrates that the groups of technology classes exhibit similar pre-war patent counts; this is also true in terms of patenting by foreigners and by East German firms and inventors. Firm lists (see Appendix E) are more likely to contain applicants from classes with high breakup exposure. Exposed technologies were also more concentrated before the war; however the presence of IG Farben fully explains these differences. Nonetheless, wartime destruction equally affects patent applicants across the three groups. Finally, excluding from IG Farben, applicants are equally likely to be slated for post-war dismantlement.

Next, I analyze the effect of breakup exposure across technology classes on quality-weighted patent counts through difference in differences regressions. As citation counts are not available, I adjust for quality according to a text-based quality indicator (see Section 3). The subsequent results incorporate two-way fixed effects of patent class and application year; I also report interactions of application year dummies with breakup exposure. As discussed in the previous section, breakup exposure is the hypothetical change in HHI between IG Farben as one entity and broken up according to the eventual breakup structure. Empirically, the main breakup

[29]In Table C-1 in the appendix, I split technologies into high, low and zero exposure (at 75th percentile and ΔHHI = 0).

Table 5: Descriptive statistics for IG/non-IG exposed technology classes

Comparing 1925-1939 tech classes: High vs low breakup exposure					
N=33 (H) 102 (L)	High exp.	Low exp.	Difference	(SE)	p-value
Granted patents (p.a.)	49.95	46.56	−3.39	(22.20)	0.879
- Domestic	37.02	33.79	−3.23	(17.44)	0.853
- Foreign	10.19	8.96	−1.23	(3.43)	0.720
- Quality-weighted	148.24	139.33	−8.91	(64.50)	0.890
Matched to firm (%)	0.64	0.33	−0.31	(0.03)	0.000
- IG Farben (%)	0.37	0.05	−0.33	(0.02)	0.000
- Other (%)	0.26	0.28	0.02	(0.03)	0.511
HHI (IG together)	1846.44	414.80	−1431.64	(249.99)	0.000
HHI (IG separate)	620.32	391.29	−229.03	(186.42)	0.221
Domestic East (%)	0.17	0.19	0.01	(0.02)	0.513
Domestic East/Berlin (%)	0.24	0.30	0.06	(0.02)	0.001
War destruction (%)	0.33	0.33	−0.01	(0.01)	0.388
Dismantle (%)	0.41	0.14	−0.28	(0.02)	0.000
Dismantle (No IG, %)	0.09	0.10	0.01	(0.02)	0.592

Notes: Shows difference between technology classes with high (above 75th percentile) and low breakup exposure. All data refers to patents applied for in 1925-1939. Patents counts are annual. Domestic and foreign patents are identified using inventor locations if available, applicant locations otherwise. Patents are weighted according to forward text similarity divided by backward text similarity, on patent-level normalized to mean three and standard deviation one. The share of matched patents refers to patents matched to the firm dataset described in Section H. HHI is calculated first assuming all IG Farben members to be one entity, then separately according to their post-1952 split-up. The location of patents is first described by the share applied for from the Eastern, Soviet sector. Berlin is handled separately due to its special, divided status. War destructions refers to the share of flats destroyed between 1939 and 1945, weighted by the patent locations in a technology class. Dismantlement on the technology class level is calculated as the share of patents by firms targeted by dismantlement. As the exposed group is strongly selected towards IG Farben patents, it is also shown considering only non-IG firms. See Table C-1 for splits in high, low and zero breakup exposure.

exposure variable is highly right-skewed. In the regressions, I use a log-transformed version of this variable so that $D_i = log(\Delta\text{HHI})$. I set $D_i = 0$ for $\Delta\text{HHI} \leq 1$. For robustness to various alternative specifications, see below. Throughout, I cluster standard errors at the technology class level (Bertrand, Duflo, and Mullainathan, 2004).

The first set of results shows specifications exposing the full dynamics of pre-trends and post-breakup differences. Figure 5 distinguishes four periods. First, during the pre-war period, IG Farben was one unified company. Then, the figure omits the patent applications during the Second World War. Wartime applications were only processed in the 1950s. As firms will only pursue applications still valuable post-breakup, patent counts are subject to selection bias. After the war follows the post-war pre-breakup period from 1948 to 1951. Finally, by 1952, most successors had incorporated and the breakup had taken effect. Using the baseline regressions with quality-weighted patent counts, Figure 5a shows insignificant pre-trends both before the war and before the breakup as well as long-run increases in patent count after the breakup.[30]

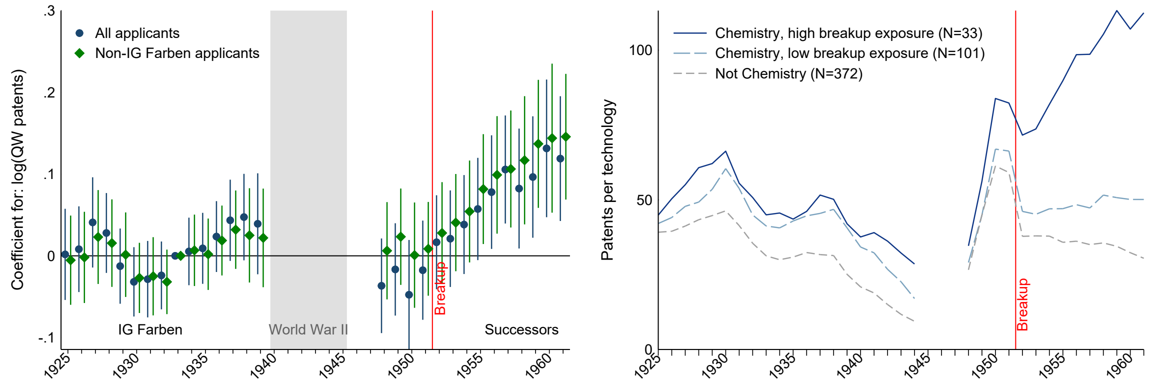
[30] In the baseline specification with a log-transformed dependent variable, there are some decreases and increases in the pre-period. With a linear dependent variable or Poisson regression, this is not the case, see Figures C-3 and C-4 in the appendix.

Panel 5b plots the average quantity of granted patents per class for the high- and low-exposure groups as well as patents outside of chemistry. Before the war, the high- and low-exposure groups showed comparable trends and levels; even the non-chemistry classes only deviated in levels. Overall, the delayed start of the effect in both panels is characteristic of innovation processes, whereby R&D investments may take time to materialize as patents. The timing of the effects further suggests that they are not tied to changes in the overall postwar order.

Figure 5: Technology class-level regressions and descriptives

(a) Quality-weighted patent count: Regression

(b) Patent counts: Descriptives



Notes: Regressions and descriptives comparing technology classes by their exposure to the IG Farben breakup. Exposure is measured using pre-war (1925-1939) data, but the breakup is finalized and effective around 1952. Panel (a) shows OLS regressions of log quality-weighted patent counts in chemical technology classes as dependent variables, and continuous exposure measures $log(\Delta\text{HHI})$ interacted with year indicators as independent variables. Shows 95% confidence intervals. The German patent office closed from 1945 to 1947. Wartime patent applications are largely prosecuted post-war and hence omitted. Panel (b) separates technologies by their breakup exposure, and shows average patent counts for patents in chemical technologies above and below the 75th percentile of ΔHHI (187) and for patents in technologies outside of chemistry.

For some analyses, I report grouped difference in differences coefficients instead of detailed dynamics for a larger set of dependent variables. Starting from Table 6, $\beta_{1948-1951}$ and $\beta_{1952-1961}$ group the respective years, showing differences to the baseline period 1925-1944. The main coefficient of interest is $\beta_{1952-1961} - \beta_{1948-1951}$. While pre- and post-war outcome variable levels are often comparable (i.e. $\beta_{1948-1951} = 0$), the war could have resulted in level shifts, making the individual β less informative about the breakup.

Results are robust to a series of variations in sample and specification. First, Table 6 reports coefficients for alternative dependent or breakup exposure variables. Further, results are robust to alternative transformations (Table C-3, e.g., unadjusted logarithms) and to binarizing the exposure variable ΔHHI and separating out zero, low and high exposure, indicating that the results are not driven by the functional form (Table C-8). Results are robust to estimation using a linear dependent variable or Poisson regression (Figures C-3 and C-4 and Table C-6). Second, the results are robust to various alternative selection of technologies, such as including all technologies, or following Baten, Bianchi, and Moser (2017)'s list of chemical technologies, or including only technologies with a significant IG Farben presence, or only technologies with many patents mentioning chemical products (Table C-9). Alternative approaches to measuring breakup exposure are discussed in Section 6.3 below.

6.1 Effect sizes

The estimated effects are substantial but not unrealistic relative to previous estimates in the historical literature and given the immense size of the shock. The difference in differences coefficient is 0.103, which for a concentration change of ΔHHI = 200 corresponds to a 73% patenting increase relative to a technology without concentration change. This figure amounts to 34.4 additional patent grants per technology class and year. While these estimates are large, they have to be seen in context. One in six patents in chemical technologies was associated with IG Farben, and many more in highly affected areas. IG Farben and associated companies offered more than a third of products listed in product catalogs, and a third of those saw increased competition. In addition, the breakup took place in a situation where no dedicated competition law had been in place in Germany. The first such law was enacted only in 1958, towards the end of the sample period. The strong intervention in a generally weak antitrust environment is consistent with large effect estimates.

Further, the results are of a comparable magnitude relative to other findings in the historical literature. Watzinger, Fackler, et al. (2020) find that compulsory licensing of Bell patents leads to 3.2 patent applications per year more for a mean dependent variable of 6.8, an increase of 47%. Focusing on the breakup of AT&T/Bell itself, Watzinger and Schnitzer (2022) find an increase of more than 70 patents per year for a mean of almost 120, an increase of 60%. These comparable shocks yield estimates of similar magnitude. Further estimates in the historical literature, besides the ones already mentioned, are much less than an order of magnitude away from the headline estimates and may constitute similar or weaker shocks than the breakup. For example, compulsory licensing of German technologies after WW1 increased US innovation by 20% (Moser and Voena, 2012), whereas German innovation increased by 30% (Baten, Bianchi, and Moser, 2017). Jewish immigration in the US increased innovation by 31% (Moser, Voena, and Waldinger, 2014).

In contrast, the literature studying current-day mergers tends to arrive at directionally consistent, albeit smaller, estimates. Haucap, Rasch, and Stiebale (2019) study merger events and analyze patent applications by merged entity and competitors relative to matched control firms. They find large decreases in innovation output for the merged entity (around 30% - up to 44% after propensity score matching) and more moderate reductions for competitors (around 7% - up to 25% after propensity score matching). Igami and Uetake (2020) study, as part of their counterfactual analysis, the effect of increased or reduced merger thresholds according to the number of active firms in the market and find smaller effects. If mergers to monopoly were permitted, in their simulations, about 7% fewer innovations would occur relative to a baseline threshold of $N = 3$; 10% fewer relative to a $N = 6$ threshold. However, due to more stringent antitrust enforcement, recent mergers have much smaller effects on market and technology structure compared to the IG Farben breakup.

6.2 Robustness checks related to the historical context

I test whether the main results are robust to the inclusion of control variables capturing historical factors. For each control variable, I discuss the specific historical context and the role of IG Farben itself in detail. Due to its length, this discussion is relegated to Appendix H. Table C-2 in the appendix summarizes the results of including the control variables; in these regressions, the main coefficients of interest remain similar to the baseline specification. As control variables, I first construct measures of exposure to war destruction based on city-level damage estimates (Kästner, 1949; Hohn, 1991). Second, I quantify the extent of Allied policies aimed at reducing the German war potential. For this, I digitize lists of firms slated for dismantlement in the occupation zones (Harmssen, 1951) and assign shares to technologies and dismantlement dummies to firms. I also test whether the results are robust to the exclusion of technological fields, particularly plastics - which were specifically targeted by postwar regulation. Third, I assign patents to the respective occupation zones and quantify the exposure of technologies or firms to the division of East and West Germany. Fourth, I employ the firm-level count of pre-war US patents to quantify the exposure to confiscation of foreign IP or the post-war expropriation of German IP (Gimbel, 1990). Relatedly, I analyze the speed of patent prosecution to test whether patent office-related factors might differentially affect technologies. I also reject the hypotheses that additional Allied competition policy - the 1947 dissolution of cartels - or policy related to internationalization - the 1951 entry into the General Agreement on Tariffs and Trade (GATT) - are confounding factors. Both require product-level analyses involving prices; see Section 4.1. In Appendix H, I also discuss unquantifiable historical evidence, including the Nuremberg trials, wartime loss of life, technological opportunity, post-war growth, and IG Farben itself as a dismantlement target.

6.3 Alternative exposure variables

While intuitively appealing, ΔHHI does not directly conform to the identification justification of an idiosyncratic breakup of IG Farben along the occupation zones. ΔHHI, as used in the previous analysis, has the advantage of its close relationship to the prior industrial organization

Table 6: Effects in technology class-level regression: Main results

log(Patents)	(1) Exposure: log(ΔHHI) 1925-1939 All (Quality)	(2) Non-IG (Quality)	(3) All (Count)	(4) Non-IG (Count)	(5) 1930-1939 Non-IG (Quality)	(6) 1925-1935 Non-IG (Quality)	(7) 1948-1952 Non-IG (Quality)
β_{48-51}	−0.039	0.006	−0.023	0.015	0.003	0.007	0.015
	(0.023)	(0.021)	(0.023)	(0.020)	(0.020)	(0.019)	(0.020)
β_{52-61}	0.064	0.091	0.072	0.095	0.089	0.086	0.091
	(0.025)	(0.023)	(0.024)	(0.023)	(0.023)	(0.022)	(0.025)
$\beta_{52-61} - \beta_{48-51}$	0.103	0.084	0.094	0.080	0.086	0.078	0.076
	(0.021)	(0.022)	(0.019)	(0.019)	(0.021)	(0.021)	(0.022)
Tech FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Classes	135	135	135	135	133	135	134
Dep. var. mean	4.167	4.041	3.060	2.935	4.051	4.041	4.048
Adj. R-Square	0.793	0.789	0.829	0.827	0.788	0.788	0.788
Observations	3757	3730	3777	3750	3715	3730	3721

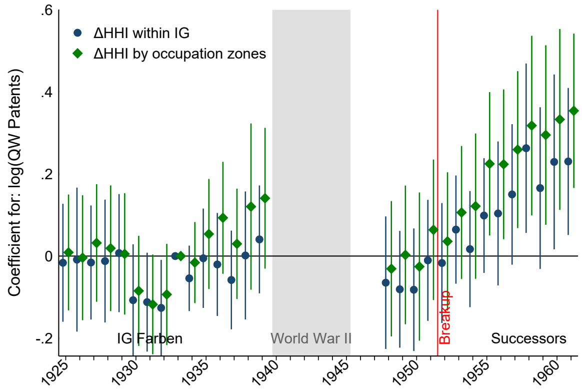
Notes: Standard errors clustered on the technology class level in parentheses. ΔHHI is the difference between technology-level concentration, considering IG Farben as one block or as broken up according to the 1952 successors. Exposure is set to zero for ΔHHI $\leq$ 1. The difference in differences coefficients in turn compare patent counts in 1948-1951 and 1952-1961 with the pre-war period. The main effect is the difference between these two coefficients, tabulated in row {52-61}-{48-51}. The dependent variables are quality-weighted patent counts, except columns (3) and (4) with simple patent counts. Quality weights are normalized to mean three, standard deviation one. The columns restrict patents by applicants, either all (columns 1, 3) or applicants unconnected to IG Farben (columns 2, 4, 5-7). The number of observations differs if for some technologies, the ΔHHI or quality scores could not be computed or for some technology-year cells, no non-zero patent counts are available. In the appendix, Poisson regression results are available in Table C-6, estimates with control variables in Table C-2.

literature. On the other hand, ΔHHI is only partially driven by the breakup along the occupation zones, as it strongly depends on the share of IG Farben patents within a particular technology. Ideally, the statistical analysis would compare between technologies with similar involvement of IG Farben but with variation in breakup intensity driven by geographic structure.

With two alternative breakup measures, I focus on variation within IG Farben. As discussed in Section 4.2, $\Delta\text{HHI}_{\text{Within}}$ considers only patents associated with IG Farben and its subsidiaries for the calculation of the HHI. $\Delta\text{HHI}_{\text{Occ}}$ additionally disregards the subsidiary structure and considers only IG Farben's geographical structure across occupation zones. Both approaches remove the amount of IG Farben investment in a particular technology from the analysis. I standardize the measures to mean zero and standard deviation one.[31] Results based on these measures are consistent with prior results: Figure 6 shows that the dynamic effect follows a

[31] In contrast to the previously used ΔHHI, the alternative exposure measures are substantially less skewed. In fact, the log transformation increases the skewness, so I do not apply it. Note that the measures are only defined for technology classes with non-zero IG Farben share. See Table C-5 in the appendix for detailed results in table format.

Figure 6: Technology class-level regressions: Alternative calculation of ΔHHI



Notes: Technology-year panel regression with 95% confidence intervals. The dependent variables are quality-weighted, non-IG patents. Continuous exposure measures are interacted with year indicators. Exposure is measured using pre-war (1925-1939) data, but the breakup is finalized and effective around 1952. The explanatory variables are standardized to mean zero and standard deviation one, see Section 4.2. The German patent office closed from 1945 to 1947. Wartime patent applications are largely prosecuted post-war and hence omitted.

gradual increase without a pre-war trend. A concentration decrease by one standard deviation increases patenting by around 20% on average over the 1952-1961 period, relative to 1948-1951.

6.4 Quantity and quality of innovation

IG Farben's breakup could have increased the propensity to patent among the company's successors and their competitors. After the breakup, the successors could no longer access each other's patents and research findings. Accordingly, the value of possessing patents increased. An increased propensity to patent among some market participants could have spilled over to other actors, as they faced an increased need to stake their claims.

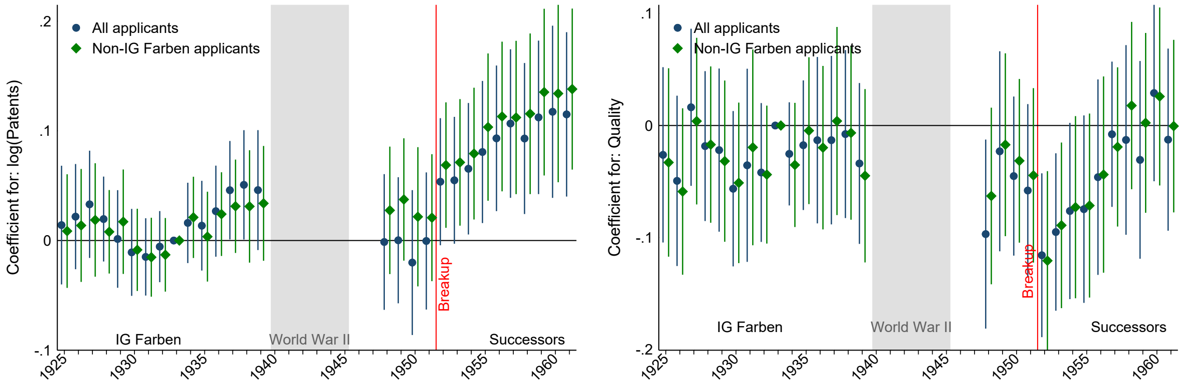
With an increased patenting propensity, differential effects across quality and quantity are possible. Raw patent counts, as well as average yearly patent quality, allow further investigation. Figure 7 presents the results of difference in differences regressions for both raw counts (Panel 7a), and for average quality (Panel 7b). The sharp increase in the raw patent count after 1952, together with the drop in the average patent quality, suggests an initial quantity-quality trade-off. The sudden increase in patents is unlikely to reflect an increase in innovation but instead points to a change in the propensity to patent.[32] Adjusting for quality attenuates the initial increase, and the overall results are consistent between raw and quality-adjusted patent counts.

[32]Alternatively, strategic delay may play a role. Firms might hold back patent applications during 1948-1951 because of uncertainties over IG Farben's future. However, this observation is inconsistent with the post-breakup drop in quality, as incentives to delay are larger for important patents. Further, there is no spike in patenting by the IG Farben successors compared to other firms (Appendix F) and the patenting increases are not exclusively driven by inventors who patented for IG Farben pre-war (Section 6.8).

Figure 7: Technology class-level regressions: Count and Quality

(a) Patent count

(b) Average quality



Notes: Technology-year panel regression with 95% confidence intervals. Panel (a) shows OLS regressions of log patent counts in technology classes by IG Farben or non-IG Farben applicants. Panel (b) shows corresponding regressions for average patent quality within classes. The analysis follows Figure 5a.

An analysis of inventor counts yields similar results. The number of inventors listed on a patent represents a classic but also an imprecise measure of investment in a particular project. Despite their higher cost, larger teams yield better results in scientific and technological endeavors (Wuchty, Jones, and Uzzi, 2007). Therefore, the number of distinct inventors active in a technology class and the average number of inventors listed on patents in a technology class present two corresponding dependent variables. Figure C-5 in the appendix reports results. The number of unique inventors in IG-exposed classes follows a similar pattern as the patent count: increases are driven by new inventors rather than by established ones. The average number of inventors per patent does not display an initial jump in 1952 but presents a slight, positive, long-run tendency. This evidence also suggests short-term increases in the propensity to patent and long-term increases in innovation effort.

6.5 Duplication of research

Next to an increase in the propensity to patent, the breakup could also have lead to increased duplication of R&D. Data on (granted) patent can only address this concern with the limitation that in a traditional patent race, only one of the contestants would be able to obtain a patent. Nonetheless, duplication of R&D may also lead to distinct but highly similar patents. In this case, the maximum text similarity of a patent to previous patents in the same technology is a proxy for potential duplication. However, this approach requires an assumption about the extent of similarity which indicates duplication. To define a natural threshold related to the institutional context, I focus on patents of addition ("Zusatzpatente"). These patents, similar to continuation/continuation-in-part patents in today's US patent system, allow applicants to extend subject matter and patent claims of a prior application, even if the patent by itself would not fulfill the novelty requirements for standard patents (See Appendix A.6 for details). By construction, patents of addition are highly similar to the patent they extend, and by themselves indicate incremental research by the original applicant. To capture 'duplication', I use the median similarity of patents of addition to their respective parent patent as a threshold. As a result, a patent is considered to be a duplicate if it has a text similarity of at least 0.57 to a patent in the same technology within the last five years. The threshold corresponds roughly to the 75th percentile in similarity to previous patents in the same technology. In contrast, the average similarity to previous patents is much lower, with median 0.18.

The estimation results suggest that duplication of research only played a small role in explaining the increase in patenting. Table C-10 in the appendix presents regression results excluding patents with similarity to prior patents in the same technology higher than the threshold defined via patents of addition. In the latter case, the estimates decrease by about -8.6% (all applicants) and -2.4% (Non-IG Farben applicants) relative to the baseline specification. In regressions with quality-weighted patent counts, the differences are smaller. Estimates are similar to the baseline when excluding patents of addition themselves.

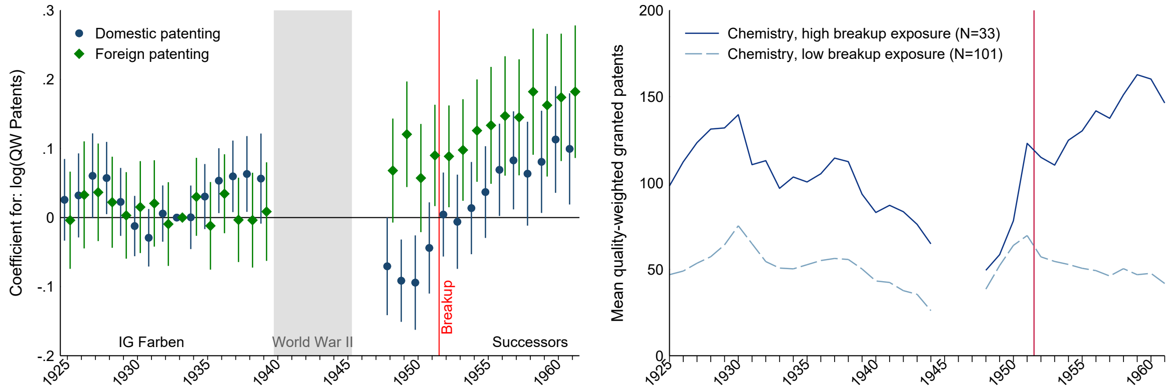
In fact, the observation that duplication of research explains only a small portion of the increase in patenting is consistent with the flip-side, i.e. that specialization within technologies increased. Appendix G.1 discusses this further. There, I use patent texts to construct a technology-level measure of specialization, thereby showing that specialization increases after the breakup.

6.6 Domestic and foreign patenting

The literature has studied the geographic source of innovation from the perspective of localized spillovers, but also with a special focus of the role of foreign competition. An extant literature, going back to Jaffe, Trajtenberg, and Henderson (1993), has found that spillovers are more likely local, and in particular often do not transcend national boundaries. Further, foreign competition and foreign entry can potentially negatively affect innovation and other economic outcomes (Autor, Dorn, and Hanson, 2013; Bloom, Draca, and Van Reenen, 2016; Autor, Dorn, Hanson, et al., 2020). These dynamics also present concerns in cases of mergers (Montag, 2021). When considering the breakup of a leading company, policymakers may question whether retaining a national champion is preferable to prevent foreign competition, even at the expense of welfare and innovation. In the context of IG Farben's breakup, this is a distinct possibility. The end of the Second World War brought the beginning of Germany's integration into the Western alliance system. However, whether the IG Farben breakup further facilitated this process is unclear.

Figure 8: Domestic and foreign patenting

(a) Regression analysis (b) Descriptive: Domestic patents



Notes: Shows quality-weighted counts of granted domestic and foreign patents, where patent location is defined by inventor location if available, applicant location otherwise. Patent quality is normalized to mean three. Panel (a) presents results from a technology-year panel regression analysis (95% confidence intervals) with $D_i = log(\Delta\text{HHI})$ (with $D_i = 0$ for $\Delta\text{HHI} \leq 1$) interacted with application year. Panel (b) shows the quality-weighted quantity of domestic patents over time, with average quality normalized to mean three. For the corresponding graph on foreign patents, refer to Figure C-1 in the appendix. The German patent office closed from 1945 to 1947.

While increased foreign patenting played an important role after the Second World War, it is less important than changes in domestic patenting in the context of the IG Farben shock. Figure 8a shows that technology classes exposed to the IG Farben shock experience a specifically large increase in foreign patenting after the war. However, this increase occurs immediately and the timing appears unrelated to the IG Farben shock. This development occurs in the context of a long-run decline in foreign patenting before and during the war. Immediately after the war, the number of patents by foreign applicants and inventors increased distinctly in exposed and unaffected technologies, although to a smaller extent for the latter. Domestic patenting develops differently, with much larger relative increases for technologies exposed to the IG Farben shock. After the war, comparison group levels immediately increase relative to those of the breakup exposure group, so that in Figure 8a the coefficients in 1948-1951 are negative. Visual inspection in Figure 8b indicates that this trend is not due to differential trends but differential levels. After 1952, the trends diverge, with the comparison group slowly decreasing and the breakup exposure group strongly increasing. Consequently, the difference between the early and late coefficients is very large (Table C-4). Overall, as the quantity of domestic patenting is larger than foreign patenting, the estimated effects also reflect quantitatively more important increases. Taken together, these results are consistent with technological spillovers, which are more likely to operate nationally than internationally.

6.7 Product market competition

The technology class level analysis conflates the effects of competition in technology space – competition for future markets – and competition in existing product markets. Firms operating in the same technologies are more likely to offer similar products. To address this perspective, I provide supporting evidence by incorporating the product catalog data into the innovation analysis, first on the technology level and subsequently by moving the analysis to the product level. Section 4.1 introduced the notion that post-breakup competition between IG Farben successors was introduced when two or more successors offer a product, contrasted with no competition increase for products that were offered only by one successor, on unaffected categories of products without any IG Farben presence. Still, the challenge remains to incorporate product-level data into the innovation analysis. To do so, I map product names to patents using full text information (see Section 3), which results in counts of product mentions per patent. I utilize this product-patent link in two ways. First, to stay within the same analytical framework advanced in this section, I construct a measure of how much a technology is exposed to products with one or multiple IG Farben successors. Second, I construct a product-level panel of patenting activity related to a given product. In both approaches, product-level competition does not seem to be a driving factor the post-breakup innovation increase.

Importantly, although the results of this section imply that *existing* product market competition was not the driving factor for the innovation increases, competition in technology space was squarely aimed at *future* markets and competition in them. For example, by 1958, Bayer obtained almost half of its revenue from products introduced in the last ten years, and not far off for BASF (see Section 7).

Technology-level measures of product market competition I construct technology-level measures which capture exposure to products with one or multiple IG Farben successors in 1952. Intuitively, exposure to IG Farben is the probability that in a random patent, a random product mention refers to a product offered by one or multiple IG Farben successors. The measures start with a patent-product link, which yields counts of product mentions N_{jk} for patent j and product k (see Section 3). As in previous analyses, I consider only pre-war patents. As patents vary in length and in their propensity to mention products, I normalize product mentions by the total number of products mentioned in a given patents, so that $s_{jk} = N_{jk} / \sum_{p \in Pr(j)} N_{jp}$, for products $Pr(j)$. For patents which do not mention products, I set $s_{jk} = 0$.[33] The exposure measure is then the sum of normalized product mentions s_{jk} which refer to products k with one

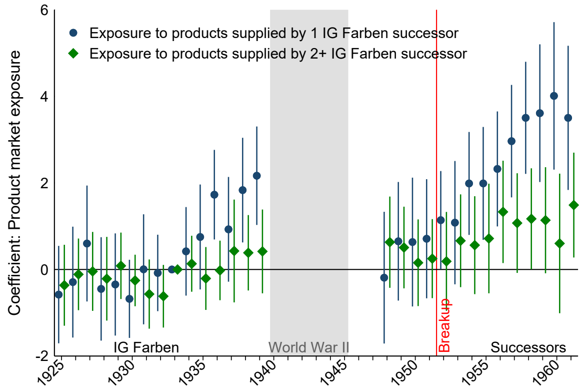
[33]Some technologies rarely mention chemical products. These tend to be more oriented towards devices or engineering, for example with applications in healthcare (technology class 30). Most do not have any IG Farben presence, so that ΔHHI = 0. The most salient exception is technology 57A ("Photographic cameras with accessories"). The main results are robust to excluding these technologies, consistent with Table C-3, columns 3-4.

or multiple IG Farben successors. For technology i, comprising patents $T(i)$, exposure is:

$$\begin{aligned} Exposure_i^{2+\text{IG}} &= \sum_{j \in T(i)} \sum_{k \in Pr(j)} s_{jk} \mathbb{1}_{\{\text{Multiple IG successors offer } p\}} \\ Exposure_i^{1\,\text{IG}} &= \sum_{j \in T(i)} \sum_{k \in Pr(j)} s_{jk} \mathbb{1}_{\{\text{One IG successor offers } p\}} \end{aligned} \tag{3}$$

On average, exposure to products with one IG Farben successor is slightly higher ($\mu_{Exp}^{1\,\text{IG}} = 0.25$, $\sigma_{Exp}^{1\,\text{IG}} = 0.16$) than for exposure to products with multiple IG Farben successors ($\mu_{Exp}^{2+\text{IG}} = 0.16$, $\sigma_{Exp}^{2+\text{IG}} = 0.11$). The product-based exposure measures are highly correlated with the exposure measure from the previous analysis $log(\Delta\text{HHI})$, which was calculated based on the distribution of IG Farben's patent portfolio across (eventual) successor companies. The correlation coefficient for $Exposure^{2+\text{IG}}$ is 0.63, compared to 0.48 for $Exposure^{1\,\text{IG}}$. The correlation with the overall exposure to IG Farben $Exposure^{1\,\text{IG}} + Exposure^{2+IG}$ is 0.77.

Figure 9: Technology-level regressions with product market exposure



Notes: Shows regressions of (log) quality-weighted counts of granted patents from applicants not associated with IG Farben. Product market exposure is the (weighted) share of patents mentioning a chemical with post-breakup competition (green diamonds, $\sigma_{Exp}^{2+\text{IG}} = 0.11$) or only one post-breakup successor (blue circles, $\sigma_{Exp}^{1\,\text{IG}} = 0.16$). The analysis follows Figure 5a, for further details see Table C-11. Shows 95% confidence intervals.

The results indicate that competition in existing product markets is likely not the driving factor behind the increases in innovation. The estimation still follows Equation 2, but replaces exposure D_i by $Exposure_i^{2+\text{IG}}$ and $Exposure_i^{1\,\text{IG}}$. Figure 9 shows that in technologies with increased exposure, patenting remains unchanged in the pre-breakup (post-war) period, but increases significantly after. However, exposure to products with one IG Farben successor leads to *larger* patenting increases than exposure to products with multiple IG Farben successors.[34] Competition in existing product markets did not lead to disproportionate increases in innovation.

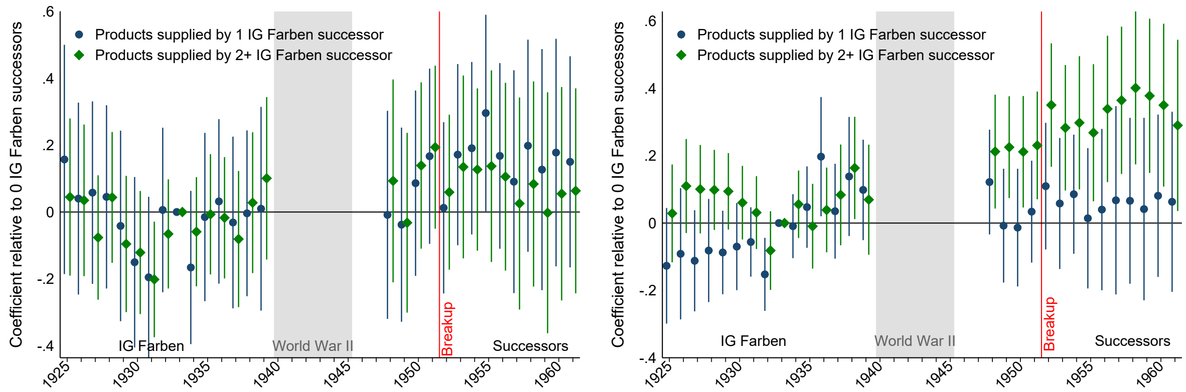
[34]For the latter, the difference between post-breakup and pre-breakup coefficients is also not statistically significant (Table C-11). Results are qualitatively similar when restricting to technologies with at least 20% (50%) of patents mentioning a product, and when limiting the list of products under consideration to chemical substances.

Rather, taken together with the previous analyses, the results are consistent with technological competition for future markets and resulting technological spillovers.

Product-level innovation analysis Next, I move the analysis to the product level. In such a specification, it is possible to operationalize exposure to product market competition directly via the number of IG Farben successors (multiple, one or zero) rather than through aggregation procedures. In contrast, innovation related to a product is measured by the weighted number of mentions of a product in patents. As a result, the analysis still follows Equation 2, but on the product level p instead of the technology level. Further, exposure D_p is replaced by the binary variables $\mathbb{1}_{\{\text{Multiple IG successors offer } p\}}$ and $\mathbb{1}_{\{\text{One IG successor offers } p\}}$, and the regression is estimated using Poisson rather than OLS with log-transformed Y_p as the number of zero-valued observations is large. However, as IG Farben patents also frequently mention products not supplied by IG Farben, this specification allows focusing on the innovation output of IG Farben itself.

Figure 10: Product-level regressions

(a) Regression analysis: IG Farben patents (b) Regression analysis: Non-IG Farben patents



Notes: Shows regression analysis of quality-weighted and and mentioning frequency-weighted counts of patents mentioning products in a product-year panel, estimated using Poisson regression (95% confidence intervals). The regressions compare patent counts for products supplied by multiple IG Farben successors (green diamond) or one IG Farben successor (blue circle) to products not supplied by any IG Farben successor. Figure 10a shows the results from a regression analyzing patents applied for by a firm associated with IG Farben or one of the successors, whereas Figure 10b shows the results from a regression analyzing non-IG Farben patents. For results excluding product categories, see Figure D-1. For further details, see Table D-1.

Similarly to the technology-level analysis, the results suggest that exposure to the breakup in the existing product market is not related to strong post-breakup increases innovation related to these product markets. Figure 10 reports coefficients for patents by IG Farben and by other firms and suggests that at most, there is a small increase in non-IG Farben patents mentioning products with post-breakup competition.[35] For IG Farben patents, there is no increase whatsoever, so

[35]See also Table D-1 in the appendix. While there are positive coefficient estimates for patents mentioning products related to IG Farben but without post-breakup competition ($\beta^{1\,\text{IG}}_{52-61} - \beta^{1\,\text{IG}}_{48-51}$), the difference between the two is not statistically significant at conventional levels. Results are robust to excluding product categories (Table D-3 and Figure D-1 in the appendix), where the absence of competition-related increases is even more pronounced.

that the post-breakup increase in patenting by IG Farben (see Section 7) seems unrelated to post-breakup competition in existing product markets.

6.8 Inventors

I test whether the innovation effect is driven by inventor mobility. Inventors of IG Farben may have started patenting at other companies, which may be the underlying mechanism for the increased non-IG Farben innovation output. In this case, the effect should either be associated with former IG Farben inventors themselves, or alternatively with companies that they moved to. To test this, I track inventors primarily using patent documents, but I also digitize membership lists of the German Chemical Society to track inventors who no longer patent.

Descriptively, some inventors indeed switch to non-IG Farben firms, but the numbers are comparatively small. Of 1,331 inventors working for IG Farben between 1935 and 1945, only 109 (8.2%) patent with a non-IG Farben affiliation after the breakup.[36] On the other hand, it is possible that inventors switch to other companies without patenting. It is not feasible to gather a fully comprehensive dataset on inventor careers from non-patent data, but membership lists of the German Chemical Society allow a cautious approach. Of the 1,331 pre-war IG Farben inventors, about 350 occur in either 1950 or 1953 edition. Most importantly, while many inventors no longer work for IG Farben, essentially none switch from IG Farben to another company between 1950 and 1953. Figure A-5 provides a visualization.

IG Farben inventors themselves do not seem responsible for the post-breakup increase in patenting at other firms, nor is the effect associated with firms that saw significant inflows of IG Farben inventors. Excluding inventors that worked for IG Farben pre-1945 leaves the regression results virtually unchanged (See Figure 11a). Similarly, in the firm-level analysis, I do not find that patenting by IG Farben inventors at affected non-IG Farben firms increases (Table E-3). Firm-level exposure to IG Farben inventors (share of patents by IG Farben inventors in the pre-breakup or immediate post-breakup period) is also not associated with the innovation effect (Table E-4).

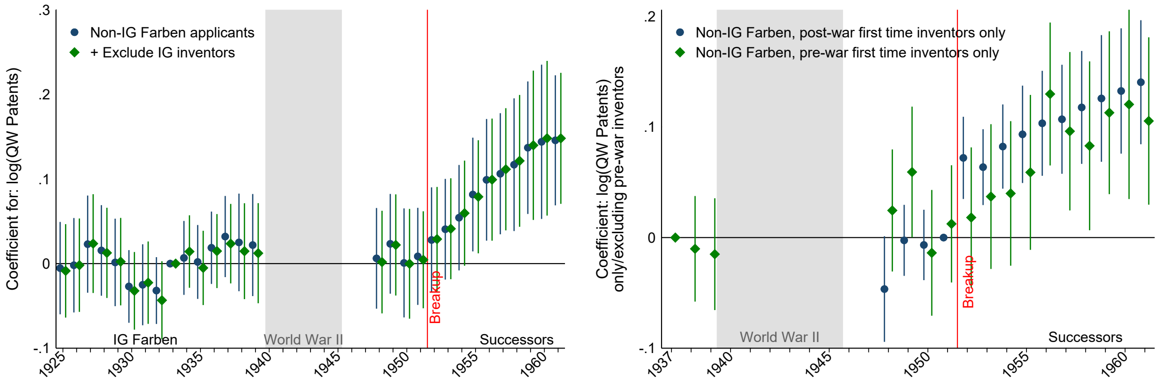
In a similar fashion, possibly inventors were not able to pursue all their ideas, for example due to the war or adverse economic conditions. To the extent that the timing of the breakups coincides with a change in circumstance, the post-breakup increase could be fueled by the availability of such stored ideas. To test whether this is the case, I focus the regressions on either patents by inventors that were already active before the war, or such that started patenting

[36]In fact, more than half of inventors do not patent again after the war, likely due to retirement. Focusing on inventors still active after the war shows a similar picture: Of 966 inventors working for IG Farben between 1948 and 1951, 55 (5.7%) patent with another firm after the breakup.

after 1945. Figure 11b suggests that trends between technologies differentially affected by the breakup are similar in both groups.

Figure 11: Technology class-level regressions: Quality-weighted patent counts

(a) Exclude IG Farben inventors (b) Only pre-war/post-war inventors



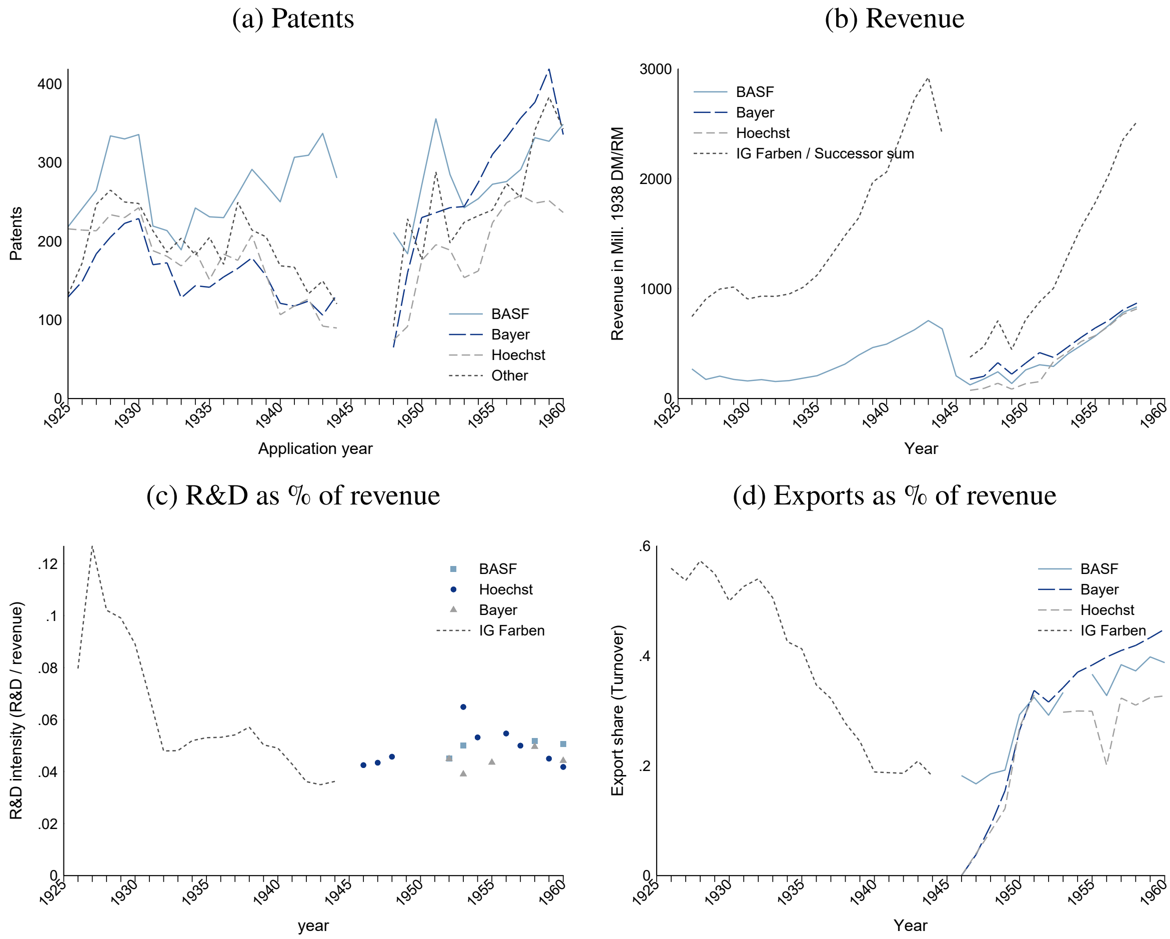
Notes: Shows regressions of (log) quality-weighted counts of granted patents from applicants not associated with IG Farben. Figure 11a further excludes inventors that ever worked for IG Farben (green diamonds). Figure 11b focuses on inventors who patented for the first time after the Second World War (blue circles) or who patented for the first time prior to the Second World War (green diamonds). Coverage of inventor data outside of IG Farben is comprehensive only starting 1937. The analysis follows Figure 5a. Shows 95% confidence intervals.

7 Innovation by IG Farben

The breakup's economic effect on IG Farben is difficult to study causally, as appropriate control groups are hard to find. Despite IG Farben's size, the number of successor companies is too small for statistical analysis. However, with descriptive analysis of financial and patent data, it is possible to contextualize the development of IG Farben and its successors. In this section, I further discuss the specialization of IG Farben's patent portfolio.

IG Farben and its successors were highly innovative companies with high R&D intensities, both before and after the breakup. At the peak of IG Farben's strength in the late 1920s, R&D spending reached 8-12% of revenue, over 50% of which was derived from exports (Figure 12). In the 1930s and 1940s, domestic turnover rose while export shrank in the context of the great depression and Nazi autarky policy. R&D continued to play an important role, though at more moderate levels than before. The immediate post-war statistics reflect the economic difficulties and the rapid return to pre-war levels (Figure 12). After the war, turnover collapsed, and export links were disrupted. However, as with the overall economy, recovery was quick enough that by the early 1950s, the Western IG Farben successors returned to mid-1930s turnover and export shares. Over the following decades, all successors became globally successful corporations. Successors' R&D intensities and patenting levels initially remained comparable to before the war, with large increases in patenting and high but constant R&D intensity thereafter. IG

Figure 12: IG Farben and its successors over time



Notes: Data as available from secondary sources. 12b: IG Farben after 1945 is the successors' sum. Source: ter Meer, 1953 (Data on IG Farben before 1945), Abelshauser, 2003 (BASF turnover), Stokes, 1988 (Exports, turnover), FAZ/ZEIT newspaper archives (Post-war R&D and turnover), Statistical yearbooks (Inflation), own calculations based on Section 7 (Patents).

Farben's patenting also increased relative to a synthetic control group constructed from the German electronics industry. The electronics industry was dominated by a duopoly of AEG and Siemens (Feldenkirchen, 1987), who were spared from Allied breakups, yet similarly affected by war-related shocks. In fact, these two companies were the only two with comparable patenting amounts to those of IG Farben. Patenting by IG Farben and the synthetic control developed in parallel during the pre-war and pre-breakup years but increasingly diverged after 1952, when patenting among the IG Farben successors strongly increased. I report details of the analysis in Appendix F.

After the breakup, innovation and new product markets played an important role for the IG Farben successors, consistent with important and impactful R&D efforts. The importance of new product markets becomes clear from reports about their contribution to revenue. For example, by 1958, Bayer's revenue from products introduced in the last ten years was reportedly close to 50%. At the same time, BASF was earning 40% of its revenue from novel technologies.[37] Further, the successors continued to work in the same technologies, although with specialization within, and maintained similar product portfolios. Appendix G.1 shows that when considering the pairwise cosine similarity between the technologies the successors patented in, similarities remain around 0.9 after the breakup. In contrast, when considering the text content of the patents, the cosine similarity starts at 0.9 before the breakup and drops to 0.7 over the next ten years. The product portfolio overlap remained high even ten years after the breakup. For example, the overlap between BASF and Bayer moved from 41% to 42%, whereas Bayer-Hoechst dropped from 41% to 29% and BASF-Bayer dropped from 38% to 32% between 1952 and 1961.[38]

8 Conclusion

In this paper, I study the effect of the IG Farben's 1952 breakup on innovation. The horizontal division of IG Farben's different R&D locations created competition within technology classes, which strongly increased innovation in affected technology classes. Innovation effects incorporate short-run quantity-quality trade-offs and are driven by changes in domestic patenting. The breakup also created substantial competition in existing product markets and led to price decreases, which however did not seem to be a primary driver of the innovation effects. The results are consistent with technological competition directed at future product markets and technology spillovers leading to increased aggregate innovation.

Naturally, the historical context of the IG Farben breakup is fraught with potential confounding factors. As such, any analysis remains afflicted by limitations. However, it is possible to analyze the historical context to assess the strength of confounding factors. The impact of some factors can be quantified for robustness analyses, while others can be understood more clearly in the historical context. Robustness analyses, in turn, introduce control variables for the effects of war destruction, Allied occupation and competition policies, and the Soviet sector. Since the observed effects only materialize after the breakup and effects are driven by technologies where the IG separation increased competition, it is unlikely that a single factor from the historical context can explain the set of observed effects better than the IG Farben breakup itself.

[37]See *Frankfurter Allgemeine Zeitung* (newspaper) of April 11, 1959 on Bayer and of February 4th, 1959 on BASF.

[38]All calculated as the share of overlapping products among the smaller product portfolio of the two firms. For example, Bayer had 694 products listed in 1952 and 920 in 1961, whereas Hoechst had 474 in 1952 and 935 in 1961. The overlap increase from 196 products to 270 products, which results in a relative decrease. Between 1952 and 1961, likely both the number of products as well as the detail of coverage in the product catalogs increased.

The results might be lower bound estimates as IG Farben's successors did not engage in all-out competition. This was primarily due to the traditional production field specializations, but possibly also due to common ownership. Each IG Farben shareholder received stock of every successor and created latent incentives for the successors not to harm each other. Nevertheless, historically, the successors perceived each other as benchmarks and shied away from the temptation to fully re-cartelize (Abelshauser, 2003, pp. 457–478).

The historical setting of the IG Farben breakup is very relevant today. Large corporations with strong investments in in-house research continue to drive technological developments, both globally in the present time and historically in the German chemical industry of the early 1950s. Scale effects are key to success, and large firms are active in many technologies and compete in many markets. Mergers such as ChemChina-Syngenta, Dow-DuPont, or Bayer-Monsanto have focused attention on competition and innovation. On the other hand, whether findings from the IG Farben case apply to different industrial contexts such as platform industries with their pronounced network effects requires future research.

The results in this paper highlight the importance of market and technology competition and a robust antitrust policy for innovation. Specifically, an analysis of technology space and competition for future products and technologies is crucial to understand potential impacts on innovation, and the existence of multiple entities with strong R&D capabilities can be a precondition for future innovation in a technological area. Further, an analysis that assesses only the impact on the affected entity itself may miss the potentially large effects on the broader industry. Finally, the history of IG Farben represents a successful government-mandated breakup and opens questions about the role of such breakups as a last-resort instrument in antitrust toolkits. However, while single breakups can have positive consequences, a *policy* of repeated breakups may reduce incentives to invest in innovation. In IG Farben's case, the German government would later introduce formal competition legislation following the US role model and was committed to a policy environment without further breakups. Future research should study how negative dynamic incentives of breakups as a policy tool can be avoided or mitigated.

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For Online Publication

A Patent Data

The analyses in this paper require various information from individual patents. While some data could be acquired from the German patent office, much of the needed information had to be generated through image processing or OCR and subsequent text processing. These are the technology class, applicant name, inventor location, and application year. To do so, I designed a largely automated processing pipeline to deliver highly accurate information for almost all patent documents.

Figure A-1: IG Farben patent

DEUTSCHES REICH

AUSGEGEBEN AM
11. MÄRZ 1941

REICHSPATENTAMT

PATENTSCHRIFT

№ 703 500

KLASSE 12o GRUPPE 14

I 56776 IVd/12 o

Dr. Karl Köberle † und Dr. Otto Schlichting in Ludwigshafen, Rhein,
sind als Erfinder genannt worden.

I. G. Farbenindustrie Akt.-Ges. in Frankfurt, Main

Herstellung von Perylencarbonsäureestern

Patentiert im Deutschen Reiche vom 1. Januar 1937 ab
Patenterteilung bekanntgemacht am 6. Februar 1941

Es wurde gefunden, daß man reine Perylencarbonsäureester erhält, wenn man Perylencarbonsäuren mit Phosphorhalogeniden oder Thionylchlorid erhitzt und nach Beendigung der Reaktion das Umsetzungsgemisch als sol-

Man führt die Umsetzung zweckmäßig in höhersiedenden Verdünnungsmitteln, wie Chlorbenzol, o-Dichlorbenzol, Trichlorbenzol oder Nitrobenzol durch, indem man die Perylencarbonsäure mit der entsprechenden Menge

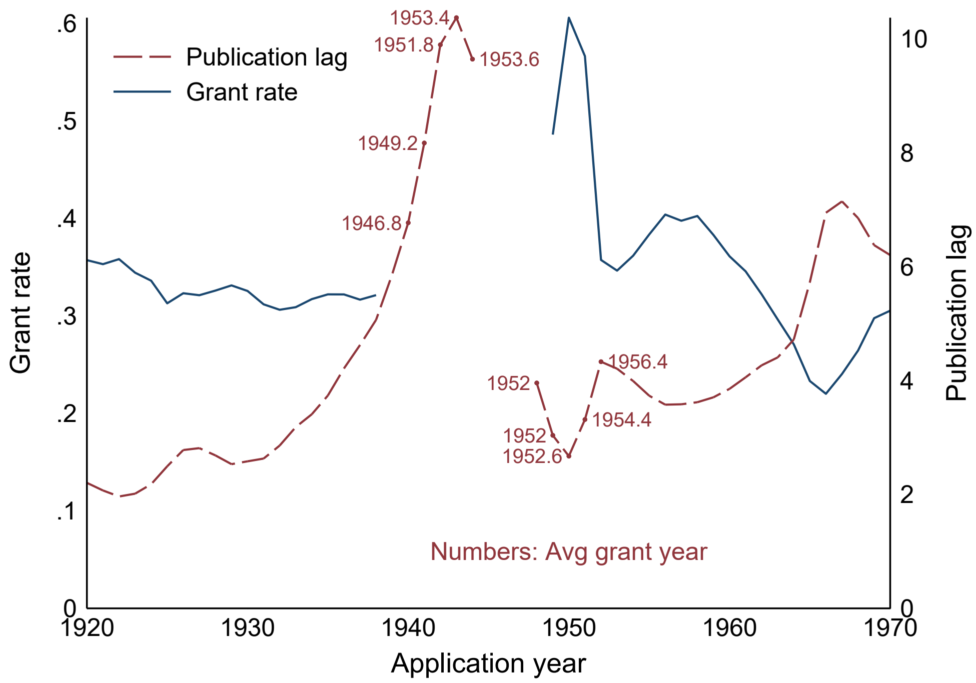
Notes: Example patent. Highlighted are technology class (12o) and group (14). Further, inventor location (Ludwigshafen) and application year (1937) are marked.

A.1 Year Information

The German patent office was first set up in 1877, although successors existed in the various German states. It handled German IP matters until mid-1945 when it closed. In 1948, when preliminary offices reopened. These accepted patent applications, but processing started only in 1950. By then, also wartime applications were processed. Therefore, patent statistics show a gap between 1946 and 1947, but are available from 1948 onwards. Figure A-2 shows the difference between application and grant year for patents where this information is available. Note the increased publication lag for wartime patents, implying that patents applied for during these years are typically granted when technological requirements have already changed. Consequently, applicants might have only selectively pursued these patents, leading to selection issues.

In historical patent records from before 1945, only granted patents ("Patentschriften") are available. To ensure a correct pre-post comparison, I disregard applications that were not ultimately granted, even when this data is available. Figure A-2 shows the grant rate by comparing the number of granted patents in the data with the number of applied patents from administrative publications. Comparing the number of granted patents (completeness of the data) is impossible as the administrative publications list granted patents by their grant year. In the long run, the grant rate remains roughly the same, although a policy of limited novelty checks at reopening yields a temporarily much higher grant rate.

Figure A-2: Patent publication lags



Notes: By application year, shows publication lag and grant rate of German patents. Publication lag is computed as difference between grant and application year, when both information is available. Grant rate is computed as a comparison of the annually filed patent applications as reported in the "Blatt für Patent-, Muster- und Zeichenwesen." 1948 and 1949 are jointly reported and thus collapsed.

A.2 Technology Class Information

The German patent office classified technologies into 89 technology areas and roughly 500 technology classes. Descriptions of these technology classes from 1910 and 1949 show that at this level, the technology classes' content remains almost always the same.[39]

The descriptions of the technology classes and the 1949 technology groups enable the classification of the technology classes into such that are directly relevant to the chemical industry. This classification includes classes from health care, photography, and agriculture relevant to the chemical industry and yields 135 classes. Appendix I lists the titles of these technologies. In addition, the paragraph on text quality measures below validates this definition with patent lists featuring significant advances in inorganic chemistry. Further, note that the main results are robust to alternative definitions, see Table C-9.

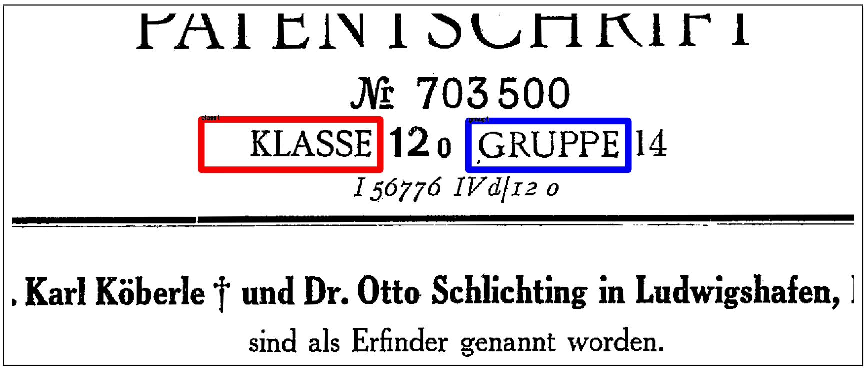
While the technology class information is printed on patent documents, making them available for data analysis presents a major challenge. Standard OCR (Tesseract) proved unreliable because the technology classes are numbers and letters without context in the middle of the document. Therefore, OCR had to be augmented with a pattern recognition algorithm designed directly for the font of the classification. Figure A-3 demonstrates the process. First, in the relevant subsection of the patent scan, the location of the technology class and group are identified. For this, image templates of the "KLASSE" and "GRUPPE" strings are matched to the scan. Over time, with the layout of the patents, the actual font and templates also change. Especially the processing of the letters is often incorrect so that they are matched to a set of templates based on problems identified in the training data. The letter font also changes over time, requiring multiple sets of templates. All areas known to be blank, for example, behind the matched latter, are painted white to remove manual markings and other noise. Finally, the remainder of the technology class string is processed using OCR. In addition to this general process, some automatic corrections are applied. For example, 3 and 8 are often confused. Also, rule-based automatic corrections remove technology class letters that do not occur in the technology class list. This process relies on OpenCV (https://opencv.org/) in combination with Tesseract (https://github.com/tesseract-ocr/tesseract).

Based on manual training data, it was possible to retrieve the technology class information with up to 95% accuracy. In most cases where the algorithm was unsuccessful, the underlying image quality is problematic, and manual processing is required. For example, many documents

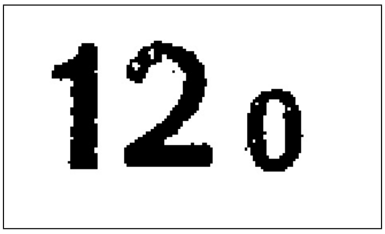
[39]Descriptions are taken two books, references are as follows. *Taschenbuch des Patentwesens: Sammlung der den Geschäftskreis des Kaiserlichen Patentamts berührenden Gesetze und ergänzenden Anordnungen nebst Liste der Patentanwälte* (1910). Amtliche Ausgabe. Berlin: Heymanns. Deutsches Patent- und Markenamt (1949). *Gruppeneinteilung der Patentklassen* 6th ed. München, Detmold, Frankfurt, Berlin: Nauck.

Figure A-3: Technology class extraction

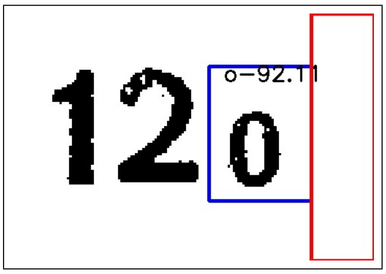
(a) Locate technology class using image templates



(b) Extracted technology class



(c) Match of letter 'o'



Notes: Process of extracting the technology class, based of the example in Figure A-1. First, the locations of the technology class within the document is identified, to reduce variance from the input documents (A-3a). As a result, the technology class snippet is extracted (A-3b). Based on extracts, the correct letter is identified (A-3c). Standard OCR can identify the remaining numbers sufficiently well.

before 1900 were manually reclassified to a finer classification system. These manual additions lead to problems, as Table A-1 shows.

Table A-1: Quality indicators for technology class processing

	All		Excluding bad input	
	Count	Correct (%)	Count	Correct (%)
1877-1900	172	77.33	138	93.48
1901-1920	531	92.66	514	95.72
1921-1933	275	98.18	272	98.53
1934-1945	344	97.38	342	97.95
1948-1949	780	97.69	779	97.82
1950-1954	101	98.02	97	100.00
1955-1961	478	93.10	457	95.62
later	67	98.51	66	98.48
Total	2748	94.69	2665	97.00

Notes: Quality indicators by application years of patents, based on randomly selected patent documents. The two rightmost columns exclude patents where bad input data makes correct processing impossible. The predominant reason are manual, handwritten additions (before 1900) or changes of the technology class.

For the main analysis, I rely on data on the technology classes of patents between 1925 and 1961. For the calculation of quality weights, however, patent data for the preceding and subsequent years is also required - see Section A.5. For an analysis until 1961, I extend the technology class data into the mid-1960s. Unfortunately, problems with the underlying data impede a further extension. Around 1970, the German patent office transitioned towards a new patent classification system. Many grant documents appear to be unavailable at this time - the number of available scanned documents and yearly grant counts from official statistics differ strongly. Because of publication lags, the data substantially under-reports patent grants throughout the mid-1960s. A second issue is that given the grant and publication lag of patents, grants of applications in the late 1960s applications often became public during the 1970s when only the international classes are reported on the documents.

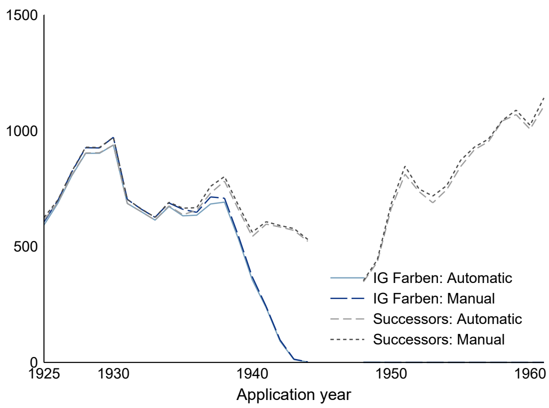
A.3 Applicant and Inventor Information

Applicant and inventor information is extracted from the OCR using machine learning. First, the precise location of applicant/inventor strings is ascertained using keywords. For example, “sind als Erfinder genannt worden” (were named as inventors) signifies that the inventors are named just before. The necessary keywords change over time as the layouts of the patents change.

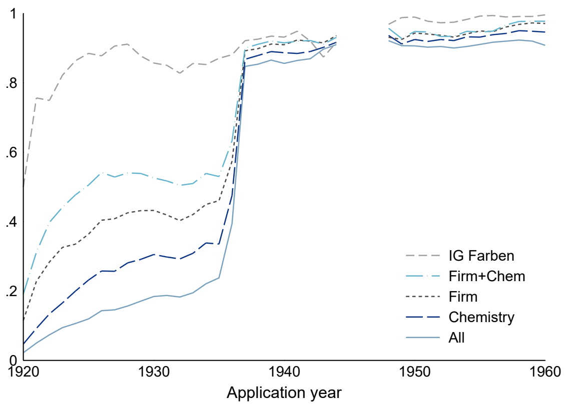
Before application year 1938, most patents do not have inventor information. Figure A-4b shows the share of patents with inventor information for different groups. For some time, supplying inventor information was voluntary, which only changed when the 1936 reform of the German patent law introduced the inventors’ right to be named. Large firms often listed the inventor of their patents already before the form. In the case of IG Farben, this information is available for about 90% of all IG Farben patents. In the remainder, the inventor information was typically intentionally omitted from the document.

Figure A-4: Patent processing descriptives

(a) Patent matching algorithm: IG Farben patents based on automatic and manual processing.



(b) Share patents with inventor information

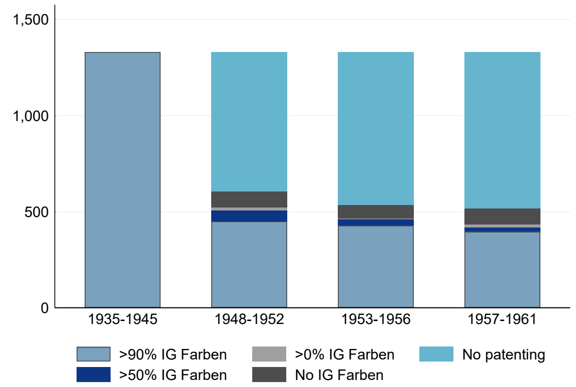


Notes: (A-4a) plots the patent counts of IG Farben and successor companies BASF, Bayer, Hoechst, Huels, Cassella and Agfa. Automatic refers to the processing pipeline above, manual to manual classification of company names based on the DPMA base data. (A-4b) plots the share of patents with inventor information, by groups. Before 1937, listing inventors was optional and was more likely done by large firms such as the IG Farben (top line). Matched firms in chemistry (second line) and matched firms overall (third line) list inventors with decreasing frequency. Patents in chemistry (fourth line) and patents overall (last line) are least likely to list inventors.

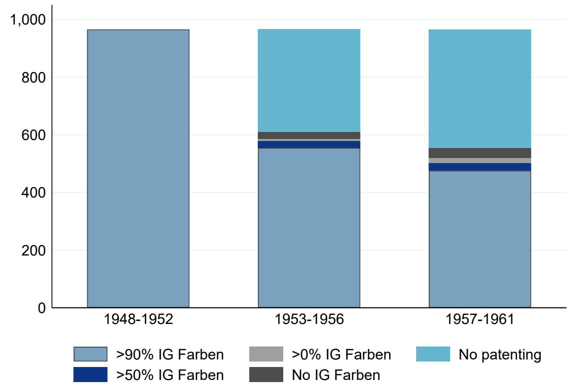
A.4 Affiliation changes of IG Farben inventors

Figure A-5: Affiliation changes of IG Farben inventors

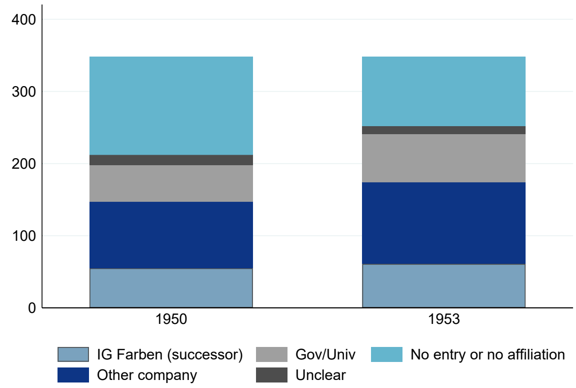
(a) Pre-war IG Farben inventors



(b) Pre-breakup IG Farben inventors



(c) Pre-war IG Farben inventors, by chemist address book



Notes: Panel A-5a shows the post-war and post-breakup affiliations of inventors that worked for IG Farben before the war. Panel A-5b shows the post-breakup affiliations of inventors that worked for IG Farben before the breakup. Panel A-5c shows the post-breakup affiliations as listed in membership lists of the German Chemical Society.

A.5 Text Analysis and Quality Measures

The first step of the text analysis is to find a numerical representation of the documents (patent full texts) to compute similarity scores between them. Text analysis is done based on Angelov (2020)'s wrapper of Doc2Vec (Le and Mikolov, 2014). Doc2Vec is advantageous compared to the bag of word (TF-IDF)-based numerical representations that are often used in the economic literature. For one, it is able to take the context of a word into account. Also, it is designed to incorporate the structure of documents. Finally, Doc2Vec has some ability to take into account different writing variants of the same word, which alleviates the necessity for stemming and lemmatization and makes it more robust against OCR errors. The calculation with Doc2Vec results in a set of document vectors v_i (normalized to unit length), between which the similarity is calculated as the cosine similarity. Note that with Doc2Vec, $\rho_{ij} \in [-1, 1]$. This differs from bag of word-based representations where all vector elements are non-negative and S_{ij} has lower bound zero.

$$\rho_{ij} = v_i \cdot v_j \tag{4}$$

Calculating a vector space for a very large number of patents computationally demanding, but converges in reasonable time for more than 350,000 full texts of patent grant documents in the time span of interest for chemical patents. To speed up the execution, multiprocessing is used, i.e. multiple processor cores run the code. This however might introduce slight numerical deviations between every training execution, even after setting seeds. The correlations of quality scores between executions are on the order of 0.85.

Quality of a patent Q_i is defined as the ratio between the forward similarity FS_i and backward similarity BS_i towards other patents in the same technology class. Forward similarity is seen as a measure of how influential a particular patent was, how much its language is taken up by subsequent patents. Backward similarity in contrast is seen as a measure of derivativeness, how much a patent took up language from previous patents.

$$\begin{aligned} FS_i &= \frac{1}{N(F_i)} \sum_{F_i} \rho_{ij} \\ F_i &= \{j : t(j) = t(i) + \tau \wedge tc(i) = tc(j)\},\ \tau \in \{1..5\} \end{aligned} \tag{5}$$

$$\begin{aligned} BS_i &= \frac{1}{N(B_i)} \sum_{B_i} \rho_{ij} \\ B_i &= \{j : t(j) = t(i) - \tau \wedge tc(i) = tc(j)\},\ \tau \in \{1..5\} \end{aligned} \tag{6}$$

$$Q_i = \frac{FS_i}{BS_i} \tag{7}$$

$tc(i)$ is the technology class of patent i, $t(i)$ is the application year of patent i. $N(F_i)$ and $N(B_i)$ indicate the cardinality of F_i and B_i, i.e. number of patents j within five years in the same technology class.

For practical purposes, the so-obtained quality scores are adjusted and normalized. They are winsorized at the 1st and 99th percentile and are standardized to have mean three and standard deviation one. This ensures that there are no negative values in any quality measure (which would occur with standardization to mean one) and that results are easy to interpret. Finally, the number of patents in 1945 is very small. For that reason, 1945 is not considered for quality scores. 1946 and 1947 are disregarded as in all other regressions as the German patent office was closed in these years. This gap is skipped for purposes of calculating the previous or next five years in equations 5 and 6. So, for a patent in 1950, the previous five years are 1949, 1948, 1944 and 1943.

These measures are inspired by Kelly et al. (2021) but differ in that instead of the total forward/backward similarity, the average forward/backward similarity are used. As long as the number of patents in the previous and subsequent years are the same, there is little difference. However, the number of patent applications at the German patent office changes considerably across years, as Figure 5b shows. Therefore, not normalizing by the amount of patent applications in consideration would incorporate future and past changes in patent numbers into current quality measures, which is not desirable for event study estimates. Since this measure is calculated within technology classes (also different to Kelly et al.), the past and future development of the size of technology classes would directly enter the quality calculation - but this is itself the base outcome measure on top of which the quality scores are applied. On the other hand, to some extent these concerns apply also to forward citation counts, which are necessarily correlated with the number of future patent applications in the close technology space. Text-based quality measure calculated based on total future similarities are conceptually closer to forward citation counts than those based on average future similarities.

Kelly et al. (2021) account for dynamically changing terminology by adjusting their measure of similarity. Their TF-IDF measures that are separately calculated for each time period, intended to reflect the updated corpus of words. While this adjustment offers an important methodological advantage, it also vastly increases computational complexity. Next to calculating a separate text model for each year, this approach is not easily integrated into the otherwise advantageous Doc2Vec methodology. A middle ground approach is to calculate the text model based on patents well before the policy change and to extrapolate it to the remaining time period. In a robustness check, only patents between 1920 and 1940 train the Doc2Vec model. This model is then extrapolated to 1941-1965 patents. With this, new words in patent texts after the policy change around 1952 do not influence the underlying similarity scores. As it turns out, regressions based on this alternative approach yield qualitatively very similar results, although the correlation between the quality scores yielded by the different approaches is only around 0.48 (0.66 for pre-war patents). Figure C-2 compares estimates based on the two types of quality scores. Quality scores take only patent grant documents into account, as the availability of application documents after the Second World War would artificially inflate quality scores.

Validating quality scores with patent lifetime and lists of notable patents The external validity of the quality scores can only be tested with additional data, for which I use indicators for the effective patent lifetime and a list of notable patents. The patent lifetime is correlated with quality as renewal fee payments are required to avoid lapses, so that the value of retaining a patent to the applicant needs to exceed a certain lower bound. Notable patents in contrast provide a judgement on quality by experts. Information on the effective lifetime is not available on patent documents. Instead, I obtain lapse dates from a separate publication series by the German patent office, the 'Patentblatt'. I digitize publications between 1950 and 1970, yielding over 200,000 lapse dates, some 65,000 of which are in chemical technology classes. For patents that had not lapsed by 1945, applicants could extend the lifetime according to the period during which the patent office was closed. To avoid additional complexity, I do not include these patents in the validation exercise. A separate publication series compiles notable patents in inorganic chemistry from 1877 until roughly 1935 (see below). Industry experts first list and then reprint the 4265 patents most relevant to industrial users. As a first test, 97.9 % of the listed patents are covered technology classes in 'Chemistry', as defined above. On the flip side, inorganic chemistry is only a subset of chemistry, but still 50.4 % of 'Chemistry' technology classes contain patents in organic chemistry. For a test of the correlation between quality scores and highlighted patents, only technology class-year pairs with at least ten patents in inorganic chemistry between 1924 and 1935 are considered. After this restriction, 2738 inorganic chemistry patents remain.[40] Table A-2 lists regression results and finds positive and statistically significant semi-elasticities between highlighted patents and their estimated quality. The correct control group would be other patents in inorganic chemistry, but this remains for future research.

Publications on notable patents:

- Bräuer, Adolf and Jean D'Ans (1921). *Erster Band 1877-1917 (Teil 1-3).* Vol. 1. Fortschritte in der anorganisch-chemischen Industrie an Hand der Deutschen Reichspatente dargestellt. Berlin: Julius Springer.

[40]The further restriction is useful as a strong positive correlation should only be expected for technology classes where inorganic chemistry actually plays an important role.

Table A-2: Validating quality scores

log(Quality)	Doc2Vec for all		Doc2Vec for $t \leq 40$	
	(1)	(2)	(3)	(4)
Patent lifetime (years)	0.011		0.010	
	(0.000)		(0.000)	
Featured patent (0/1)		0.018		0.011
		(0.008)		(0.005)
Tech-Year FE	Yes	Yes	Yes	Yes
Adj. R-Square	0.201	0.093	0.376	0.132
Observations	65241	19004	65241	19004

Notes: In columns 1 and 2, quality is based on all patents. In columns 3 and 4, quality is based on patents in 1940 and before. Featured patent is a dummy variable for being featured in a publication series listing significant advances in inorganic chemistry. Patent lifetime is the number of years between application and lapse year. The sample consists of all patents between 1924 and 1935 with at least ten patents featured in the inorganic chemistry list (columns 2 and 4), and all patents applied for since 1948 and lapsed until 1970 (columns 1 and 3).

- Bräuer, Adolf and Jean D'Ans (1925). *Zweiter Band 1918-1923 (Teil 1-2).* Vol. 2. Fortschritte in der anorganisch-chemischen Industrie an Hand der Deutschen Reichspatente dargestellt. Berlin: Julius Springer.

- Bräuer, Adolf and Jean D'Ans (1930). *Dritter Band 1924-1927 (Teil 1-4).* Vol. 3. Fortschritte in der anorganisch-chemischen Industrie an Hand der Deutschen Reichspatente dargestellt. Berlin: Julius Springer.

- Bräuer, Adolf and Jean D'Ans (1934). *Vierter Band 1928-1932 (Teil 1-3).* Vol. 4. Fortschritte in der anorganisch-chemischen Industrie an Hand der Deutschen Reichspatente dargestellt. Berlin: Julius Springer.

- Bräuer, Adolf and Jean D'Ans (1940). *Fünfter Band 1933-1937 (Teil 1-3).* Vol. 5. Fortschritte in der anorganisch-chemischen Industrie an Hand der Deutschen Reichspatente dargestellt. Berlin: Julius Springer.

A.6 Patents of Addition

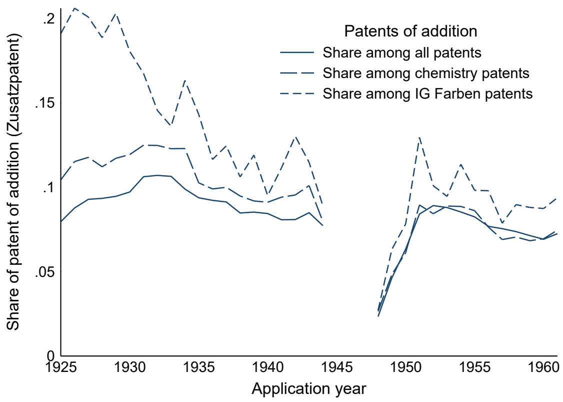
Similar to continuation/continuation-in-part in the US patent system, applicants could file for patents of addition ("Zusatzpatent") in the German patent system.[41] Patents of addition allow the introduction of additional subject matter and patent claims that are highly similar to a previous patent application by the same applicant that would not fulfill the requirements of inventive step on their own. For patents of addition, the front page of patents contains a note referencing the main patent ("Hauptpatent"). I extract information on being a patent of addition and the related main patent by extracting the corresponding information from the full-text OCR, analogous to applicant and inventor information as described in Section A.3.

During the period of interest, slightly below 10% of German patents are patents of addition, see Figure A-6a. By construction, patents of addition are highly similar to their respective main patent (median similarity=.57, see Figure A-6b) - which is consistent across the sample period (Figure A-6c).

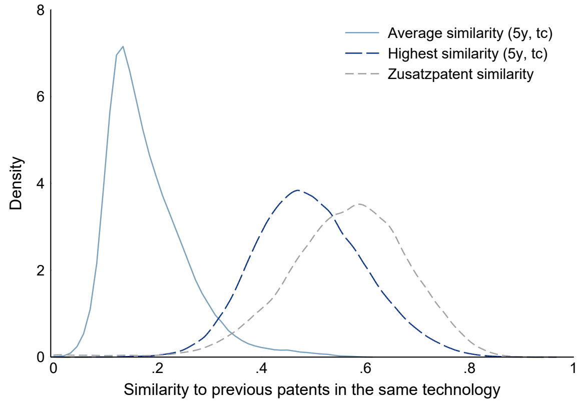
[41]This possibility was abolished in 2012 due to disuse. In the late 1950s, divisional patent applications ("Ausscheidung") became more common - for expositional simplicity, they are subsumed under the more frequent patent of addition.

Figure A-6: Patents of addition

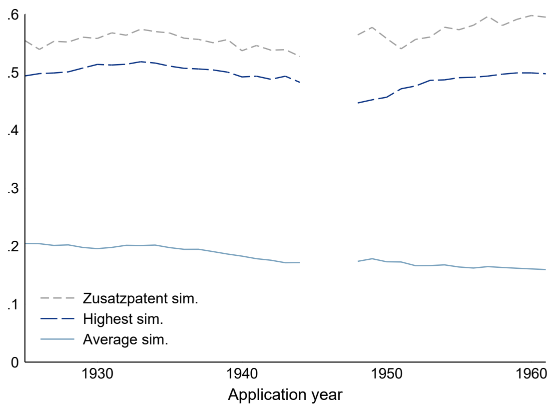
(a) Patents of addition over time



(b) Distribution of similarity



(c) Similarity over time



Notes: Figure A-6a shows the frequency of patents of addition for all patents, patents in chemistry, and patents by IG Farben (successors). Figure A-6b shows the similarity of patents of addition to their main patent in comparison to the highest similarity to any patent in the same technology in the preceding five years, and to the average similarity in the same set of patents. Finally, A-6c shows the average similarity over time for the same three types (patents of addition, highest, average).

A.7 Reassigning IG Farben Patents

During the period in question, journeys to work are typically short. Pooley and Turnbull (1999) collect historical journey-to-work records for 1813 British individuals, totaling more than 12,000 individual journeys. In Table 4 therein, they list for the 1920-1939 time period an average workplace distance of 11.1 km (London), 5.6 km (other cities with >100,000 population) and 4.4 km (Towns < 100,000 population). The overall average is 6.8 km. (Pooley and Turnbull, 1999, p. 287) In the (not tabulated) variance around these estimates, inventors are likely on the upper end. Because of this, the upper boundary for reassignment of 30km is chosen. In this light, the travel distances reported in Table A-3 are reasonable. They are slightly smaller due to the coarse measurement of inventor locations (which are available at the city or, for larger cities, city-quarter level).

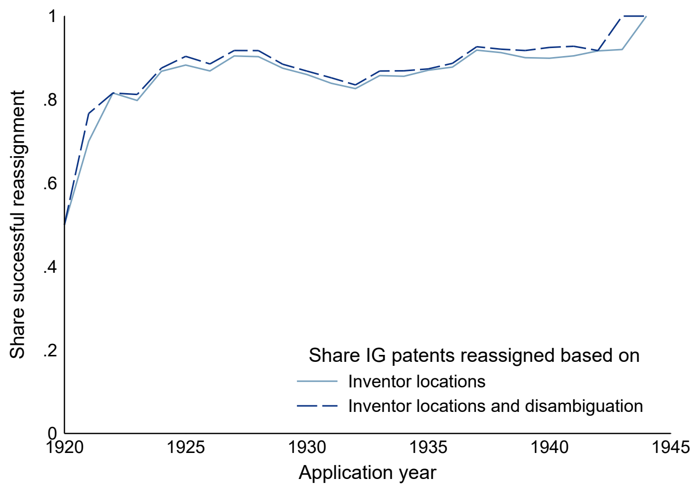
Table A-3: Distance between geocoded inventor and IG plant locations

	Mean distance	Std. Dev.	Min	Max	Total Patents
Agfa	4.24	6.12	0.07	27.32	296.00
BASF	2.60	5.59	0.02	27.81	3484.00
Bayer	1.99	3.24	0.06	24.83	2236.00
Cassella	1.47	0.91	0.01	7.78	334.00
Hoechst	3.11	4.75	0.05	27.07	2583.00
Huels	11.72	10.65	0.03	29.81	39.00
East Germany	11.17	8.53	0.02	26.67	1441.00
Overall	3.83	6.25	0.01	29.81	10 413.00

Notes: The minimum distance is often zero as inventor and plant locations are coarse and only available at the city-quarter (for large cities) or town level. East Germany subsumes several locations such as Leuna, Schkopau or Premnitz. See also map A-9.

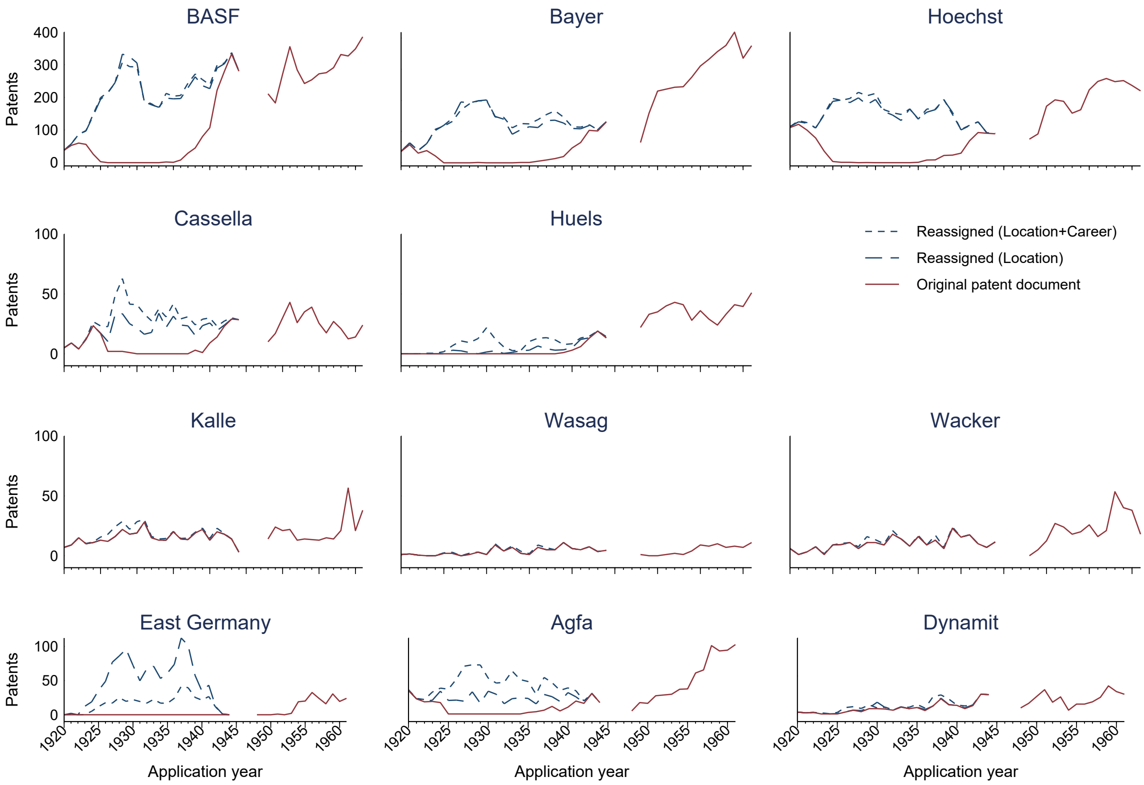
The only subsidiaries where the geographical assignment is challenged are Bayer/Agfa and Cassella/Hoechst. For Bayer/Agfa, Agfa's Leverkusen plant is at the same physical location as Bayer's Leverkusen plant. Therefore, Agfa's Leverkusen operation is subsumed under Bayer's label. Cassella is located in Frankfurt-Mainkur, a suburb of Frankfurt (Main). Hence Hoechst, located in several other parts of Frankfurt (Main), cannot fully be distinguished from Cassella. As far as possible, the deduplication of inventor profiles is used to rectify both problems. Inventors whose patents are subsequently assigned to Agfa or Cassella are also previously assigned to these companies. Map A-9 visualizes the issue.

Figure A-7: Success rate of IG Farben patent reassignment



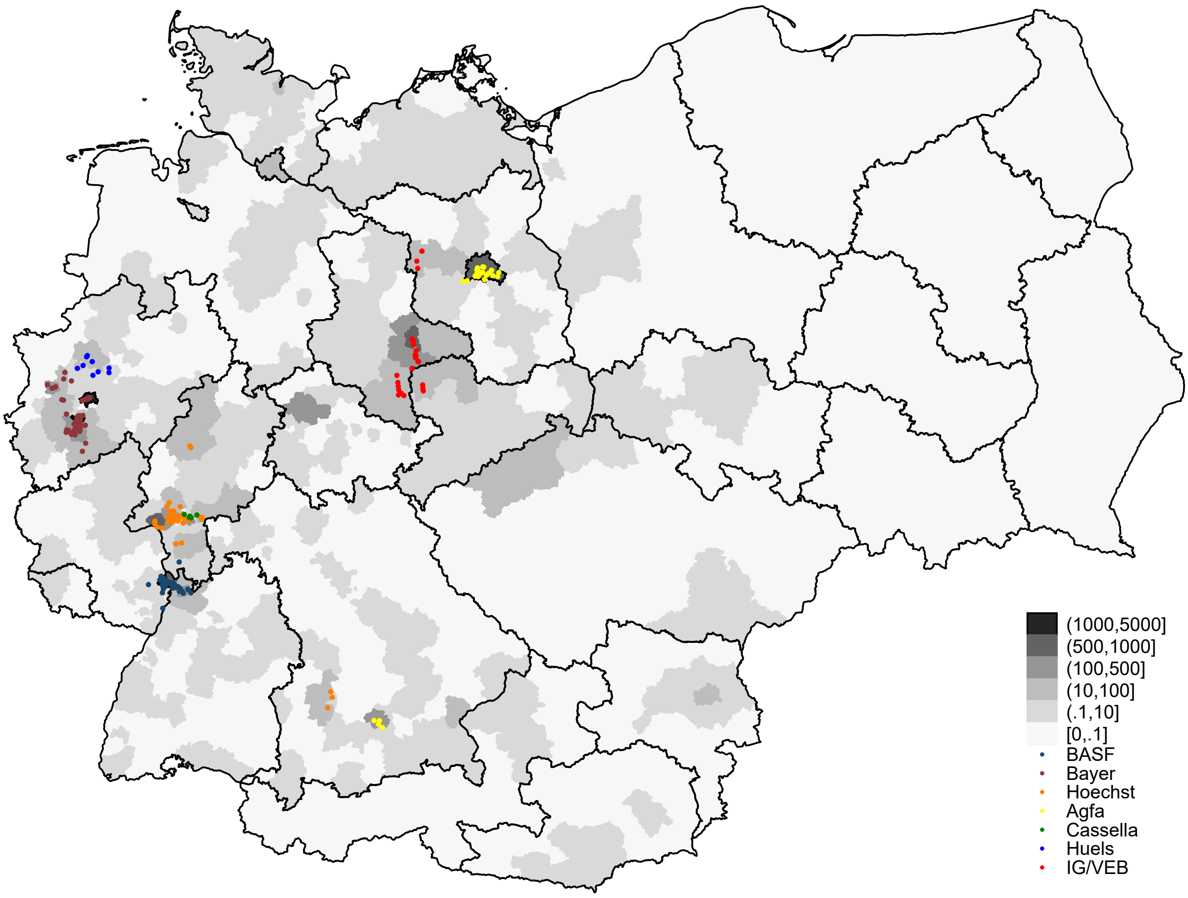
Notes: Share of IG Farben patents that could be reassigned to a successor company. Remaining patents typically have no inventor information. In some cases, inventor locations is not at any successor plant or the inventor could not observed before or after IG's existence.

Figure A-8: Patents of successor companies, assigned by inventor locations



Notes: The core IG Farben company applied all patents from the Frankfurt headquarter. However, unlike most companies at the time, almost all patents list the inventors. Due to the geographic spread of IG Farben's research facilities, inventor locations allow the reassignment to eventual successors. Only in some cases, the inventor careers from deduplicated patent applications are more informative. Here, inventors are reassigned to their post-war place of employment. The graph shows the yearly number of granted patent applications for the three large successor companies BASF, Bayer and Hoechst, and the smaller successors. Numbers are as listed on the original patent documents (red solid line), as reassigned to eventual successors using location information (blue dash line) and as reassigned to eventual successors using location information and inventor name disambiguation (solid blue line).

Figure A-9: Map: Inventor reassignment locations



Notes: Shows the location of inventors (with number of patents above a threshold) and the successor company that they are assigned to in the location-based reassignment. The background maps shows modern European regional boundaries of Germany, Austria, Poland and Czech Republic, colored with the number of IG Farben patents assigned to NUTS3 regions. Maximum intensity regions are typically not visible below the reassignment location markers. Map source: European Commission.

B Product Catalogs and Price Data

Product catalogs Product catalogs are intended for industrial purchasers and list, for a large number of chemical products, the firms supplying them. These are chemical substances and refined chemical products, such as industrial cleaners or paints. Figure B-1 shows an example of product listings. Typically, a chemical is given by its German name and translations into several other languages. Subsequently follows a list of chemical companies from which the chemical can be procured. A separate part of the book lists company contact information such as address and telephone number. I digitize the lists of firms and products for the volumes covering late 1939, mid-1952, and 1961.

The introductory remarks in each of the volumes describe the process of their creation and their content. Specifically, the remarks describe the chemical industry as producing a myriad of final products from a small set of inputs, which necessitates listing only products usual in trade (See catalog 1939, catalog 1952). The catalogs rely on the information supplied by producers, and appearance in the volume is free of charge (See catalog 1930). The books finance themselves by featuring advertisements in the books and by the sales price. The books also typically do not list foreign suppliers. Until 1932, a parallel publication series tried to keep track of global markets and foreign firms, but this effort proved too cumbersome. The books also comment on specific events impacting their publication. The 1939 edition, for example, remarks that war-related changes could not be represented in the book to not delay its publication further, whereas firms from recently occupied areas are covered (See catalog 1939).[42] The 1952 edition (Catalog 1952, editorial dated April 1952) describes itself as the first address and product listing of the West-German chemical industry since the end of the war. Turnover of firms between editions is typically high. The 1930 edition drops 1500 firms and adds 600 new ones (See catalog 1930). Based on these remarks, the listed products represent the current supplier status of Germany's chemical industry for a cross-section of common, relevant products.

Bibliographic references in this paragraph:

- 1930 catalog: *Otto Wenzels Adreßbuch und Warenverzeichnis der Chemischen Industrie des Deutschen Reiches, XVII. Ausgabe* (1930). Berlin und Wien: Urban & Schwarzenberg.

- 1939 catalog: Wegner, Hermann (1940). *Warenverzeichnis der Chemischen Industrie des Deutschen Reiches mit Angabe der Bezugsquellen.* Berlin und Wien: Urban & Schwarzenberg.

[42]As the editorial was written in December 1939, this references the recent invasion of Poland. Therefore, the volume entitled 1940 is referenced by the date of its publication, 1939.

- 1952 catalog: Barth, Werner (1952). *Firmenhandbuch Chemische Industrie in der Bundesrepublik Deutschland und West-Berlin. Adressen- und Produktenverzeichnis der Chemie-Betriebe in der Bundesrepublik Deutschland und Westberlin.* Düsseldorf: Econ-Verlag.

Figure B-1: Product listing examples in 1939 and 1952

(a) ASS, 1939

Acetylsalicylsäure [Acidum acetylosalicylicum], *e.* Acetylsalicylic acis, *f.* Acide acétylsalicylique, *sp.* Acido acetilsalicílico, *i.* Acido acetilsalicilico.
»Bayer« I. G. Farbenindustrie Aktiengesellschaft, Leverkusen-I. G. Werk [DAB. 6].
Chemische Fabrik Aubing, Aubing b. München.
Chemische Fabrik von Heyden A.-G., Radebeul-Dresden.
Gehe & Co. A.-G., Dresden-N 6.
I. G. Farbenindustrie Aktiengesellschaft, Frankfurt a. M.
E. Merck, Darmstadt.
J. D. Riedel—E. de Haën A.-G., Berlin.
Schering A.-G., Berlin N 65.

(b) Phthalic anhydride, 1939

Phthalsäureanhydrid [Acidum phthalicum anhydricum], *e.* anhydrous, *f.* anhydre, *sp.* anhidro, *i.* anidro.
I. G. Garbenindustrie Aktiengesellschaft, Frankfurt a. M.
J. D. Riedel—E. de Haën A.-G., Berlin.

(c) ASS, 1952

62. **Acetylsalicylsäure**
Acetylsalicylic acid
Acide acétyl-salicylique
Acido acetilsalicilico
Chemische Fabrik Aubing Dr. Kurt Bloch, München-Aubing
Chemische Fabrik von Heyden AG, München 23
Farbenfabriken Bayer Aktiengesellschaft, Leverkusen
Farbwerke Hoechst AG, vorm. Meister Lucius & Brüning, Frankfurt/M.-Höchst
E. Merck, Chemische Fabrik, Darmstadt

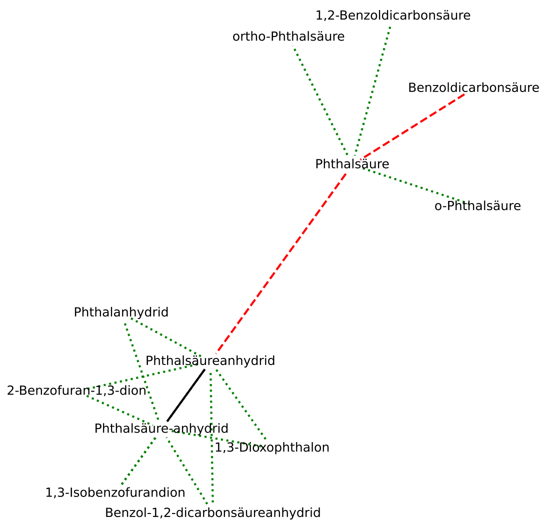
(d) Phthalic anhydride, 1952

5538. **Phthalsäureanhydrid**
Phthalic anhydride
Anhydride phtalique
Anhidrido ftálico
Badische Anilin- & Soda-Fabrik, Ludwigshafen/Rh.
Dr. Kurt Herberts & Co. vorm. Otto Louis Herberts, Wuppertal
Farbenfabriken Bayer Aktiengesellschaft, Leverkusen
E. Merck, Chemische Fabrik, Darmstadt
Ruhröl GmbH, Bottrop

Notes: Entry from 1939 and 1952, where ex-post IG Farben successors competed with each other. Acetylsalicylic acid, better known as Aspirin, is a pharmaceutical product. Phthalic anhydride is an input product to the dyestuffs, plastics and pharmaceutical industry. Acetylsalicylic acid was in 1939 offered by IG Farben (with two listings, one as "Bayer") and several others. In 1952, with Bayer and Hoechst, two IG Farben successors as well as many of the previously active non-IG suppliers offer the product. For phthalic anhydride, BASF and Bayer compete in 1952, after the product was already offered by IG Farben in 1939.

Individual product-year entries are linked between volumes using alternative names and adjusted string similarity. For example, Phthalic acid is also called Benzene-1,2-dioic acid and is cross-referenced to Phthalic anhydrate, which is Phthalic acid with one molecule of water removed. Alternative names are mostly sourced from the product books, but also from looking up product names in the German Wikipedia. Linkage using string similarity is added to deal with OCR mistakes. However, similarity between chemical names is treacherous, as for example sulfide and sulfate (German: Sulfit/Sulfat) are very similar, yet chemically different. To this end, similarity is adjusted by up-weighting the beginning and the end of substance names and by down-weighting common OCR mistakes (e.g. l vs i vs I). A set of training data is used to estimate a regularized logistic regression of a set of string similarity measures, which yields the similarity score. Only candidates with very high similarity are kept. The result of the overall procedure is a network of linked alternative names.

Figure B-2: Name network for Phthalic acid



Notes: Red dashed links are product catalog cross-references or alternative names, green dotted links alternative names derived from Wikipedia. Black solid links rely on text similarity.

From supplementary sources (Wikipedia and ChemSpider), properties of chemical substances can be extracted. This is in particular the chemical composition. The molar weight gives a first impression of a molecule's complexity. From the formula, the heaviest atom can be identified. In inorganic chemistry, especially for metal salts, this atom can drive a large part of the molar weight.

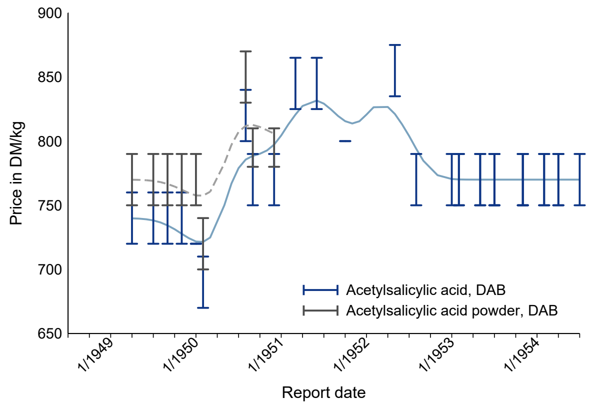
Price data Price data is taken from industry journals ("Chemie-Ingenieur-Technik", from 1953 also the insert "Chemiemarkt" to "Chemische Industrie"), where it was part of reports on the general market situation. The detailed price lists were published in a short period of time between the first removal of price controls in 1948 and ceased when prices stabilized in the mid-1950s. The price information does not intend to capture the final price paid by customers, which would depend on too many details. Instead, they describe producer prices at the factory gate. When there is substantial variance of price across producers, the lists indicate price spans.[43].

The quality of the price lists improves over time. The chaos of the early post-war period only gradually allowed the production of such lists, as high variance across firms and various disruptions rendered information notoriously unreliable. The price lists in 1948/1949 are short and sparse, whereas the later lists are more detailed and comprehensive. Both patterns lead to larger variance listed prices in the early periods. By mid-1949, however, the situation seems to have normalized sufficiently. Figure B-4 in the main text plots average prices by supplier status, where the partially extreme price levels of 1948/early 1949 are clearly visible. Most analyses will restrict to the later time periods.

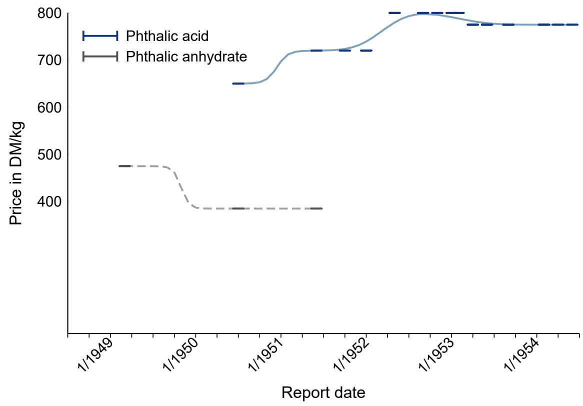
Before and during the war, government controls render price information meaningless, but data on innovation activity as well as industry structure allows tracking the German chemical industry until the outbreak of war. More high-level price data covering longer periods is available from the German Statistical Yearbook. Here, price trends before and after the war can be compared. Before the war, price controls were in place, and at since 1936 the price mechanism was effectively suspended, so that reported prices remained fixed and a pre-post comparison is uninteresting. Price controls were maintained after the war. After the war, prices as of 31.12.1944 were fixed (Fäßler, 2006, p. 42), until liberalization commenced in June 1948.

Figure B-3: Reported prices and quality information

(a) Prices for Acetylsalicylic acid



(b) Prices for Phthalic anhydrate / Phthalic acid



Notes: Shows prices reported in industry journals for two selected substances. Phthalic anhydrate is Phthalic acid with water removed. The two substances were grouped based on cross-references (alternative names) from the product books. DAB is an abbreviation for the contemporary German pharmaceutical standard (“Deutsches Arzneibuch”). When price information is given as ranges as for Acetylsalicylic acid, midpoints are used in the analysis.

[43]The discussion in this section is informed by an editorial in “Chemie-Ingenieur-Technik”, see *“Was bieten unsere Preisberichte”* (1952). In: Chemie-Ingenieur-Technik 24.1, p. 55.

The price lists report various purity levels or delivery variants, exemplified in Figure B-3. For example, Acetylsalicylic acid is available in the standard form and as powder - always in pharmaceutical grade (denoted DAB). For other products, the distinction is between in purity grades, for example ‘for technical processes’ and ‘pure’ ($\geq$ 97% product). In other cases, cross-references in the product books group very similar chemical substances together, such as Phthalic anhydrate and Phthalic acid (The former is the latter with one water molecule removed). In such cases, the time series were inspected manually and separated if different tendencies or price levels exist between purity grades. In the regression, only one time series related to Acetylsalicylic acid would occur as the ‘powder’ variant has no post-1952 data. The distinction by quality grades is typically not reflected in the product catalogs and price series are matched to the best available fit.

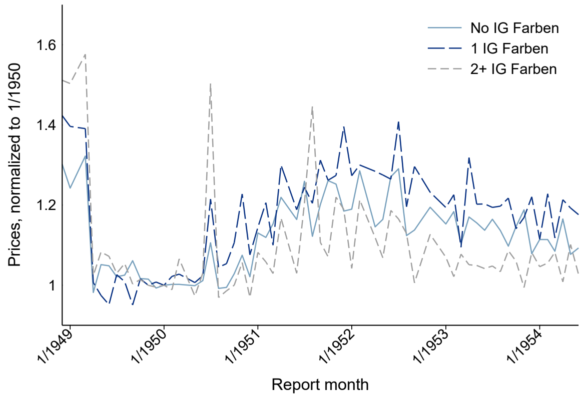
The change in availability of price time series over time requires several adjustment. In a typical month 30-40% of all prices are reported, increasing over time. For the price panel, several cleaning steps are undertaken. First, only prices for products linked to the 1952 product catalogs are kept. Price time series must have at least one observation before or in Q2/1950 and after or in Q2/1952, leaving around 560 time series. Time series with large gaps or five or fewer price entries are dropped (approximately 20). Products with extreme price changes are dropped (Factor > 4 since 01/1950, approximately 10 price series). Finally, coverage of price lists in the industry journals changes substantially after 1954Q1 and is largely discontinued, so that the time series are truncated then.

Figure B-4 displays average prices by IG supplier status over time. Products not sold by any IG Farben successor (as measured in 1952) behave similarly to products where only one IG Farben successor was present. If at all, price trajectories are above the ‘no IG’ group. However, products where the IG Farben breakup created product-level competition are on a different trajectory. While prices overall increase in 1951, they do not participate in that price increase to the same extent. Visually, the start of divergence of the price trajectories seems to occur earlier than the breakup finalization (early 1952). Instead, it coincides with the breakup announcement and the enactment of its legal basis in August 1950.[44] In price regressions, the first year of the post-period is accordingly set to the third quarter of 1950.

[44]Law 35 of the Allied High Commission (“Disperson of Assets of I.G. Farbenindustrie A.G.”), dated 17th of August 1950. The executive order finalizing the process is dated 17th of May 1952. The legal documents are retrievable at http://deposit.d-nb.de/online/vdr/rechtsq.htm.

Figure B-4: Raw price data descriptives

(a) Prices by 1952 IG Farben status



Notes: Average prices reported in a month. Prices are normalized to the closest data relative to January 1950. There, a very short price list leads to a very large outlier. Products are grouped by the occurrence of IG Farben (or subsidiaries and successors) as suppliers in 1952.

B.1 Supplementary Results

Table B-1: Exposure to post-breakup competition; conditional on 1952 IG Farben status; chemical substances only

Products listed in 1952

	IG Farben Products (N=923)			Other Products (N=1664)		
	No IG	One IG	2+ IG	No IG	One IG	2+ IG
1952	0%	74%	26%	100%	0%	0%

Products listed in 1939, 1952, and 1961

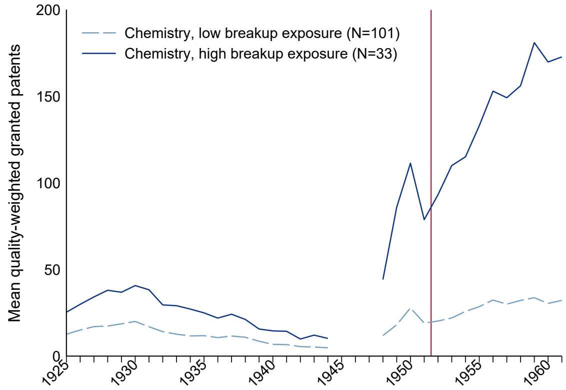
	IG Farben Products (N=259)			Other Products (N=494)		
	No IG	One IG	2+ IG	No IG	One IG	2+ IG
1939	30%	57%	13%	85%	14%	1%
1952	0%	65%	35%	100%	0%	0%
1961	29%	37%	34%	94%	5%	1%

Notes: Describes the number of IG Farben successors, split by whether products were offered by IG Farben-connected companies in 1952. The upper half of the table focuses on all 1952 products (excluding brands and categories of differentiated products), whereas the lower half focuses on a balanced table of products offered in 1939, 1952, and 1961. Rows tabulate the status in 1952 (upper half) and 1939, 1952 and 1961 (lower half). The first set of columns focuses on products offered by IG Farben in 1952 and shows shares by current supplier status. The second set of columns looks at products only offered by other companies in 1952, again showing shares.

C Supplementary Results: Innovation in Technology Classes

Figure C-1: Foreign patenting and incumbent vs. entrant

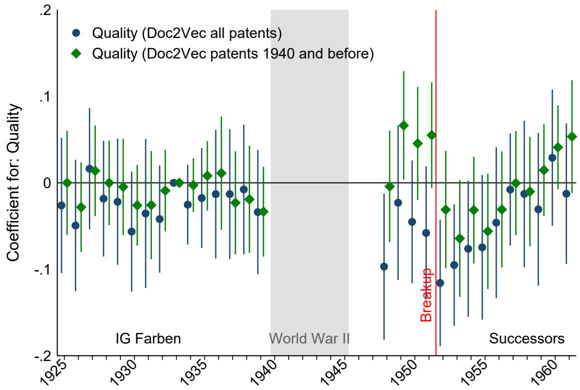
(a) Foreign patents



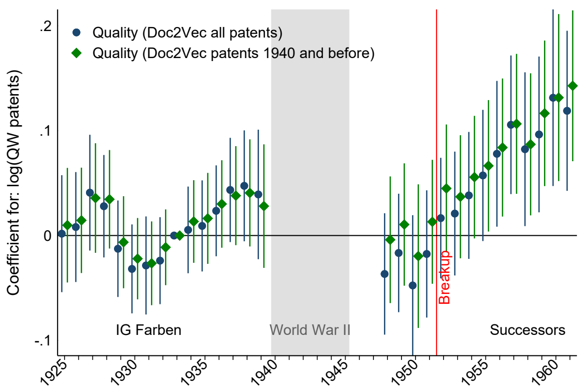
Notes: Average quality-weighted patents in technology classes with high and low exposure to the IG Farben breakup, as defined by the 75th percentile of ΔHHI (187). Exposure is measured using pre-war (1925-1939) data, but the breakup is finalized and effective around 1952. Average quality is normalized to three. Domestic/Foreign is determined based on applicant and inventor locations where possible. The German patent office closed from 1945 to 1947.

Figure C-2: Event studies: Alternative calculation of quality scores

(a) Average quality



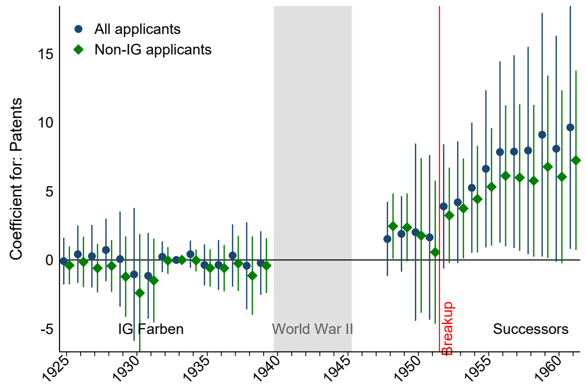
(b) Quality-weighted patents



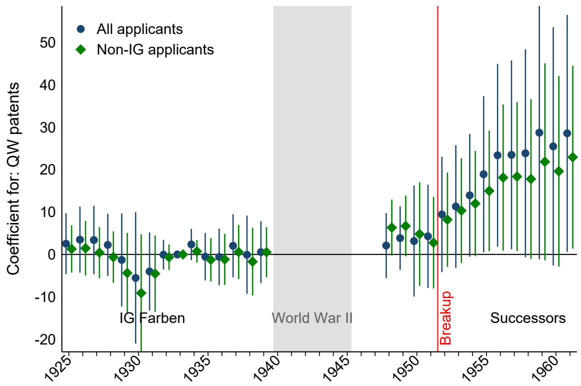
Notes: Technology-year panel regression with 95% confidence intervals. Regressions comparing technology classes by their exposure to the IG Farben breakup, as defined as $D_i = log(\Delta\text{HHI})$ with $D_i = 0$ for $\Delta\text{HHI} \leq 1$. Exposure is measured using pre-war (1925-1939) data, but the breakup is finalized and effective around 1952. Round estimate markers rely on quality-scores where the Doc2Vec model was trained on the full corpus of chemical patents. Diamond estimate markers rely on a Doc2Vec model trained only with patents until 1940 and extrapolated for later years. Patent quality is winsorized and rescaled within technology classes to have average three and standard deviation one to exclude negative values. C-2a shows average yearly quality within technology classes as dependent variable. C-2b shows quality-weighted counts of granted patents. The German patent office closed from 1945 to 1947. Wartime patent applications are largely prosecuted post-war and hence omitted.

Figure C-3: Event studies: Linear estimates

(a) Patent count



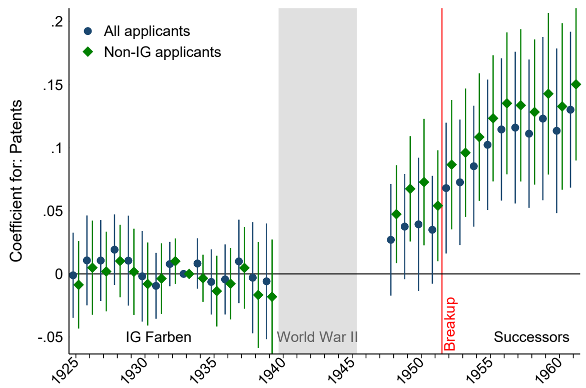
(b) Quality-weighted patents



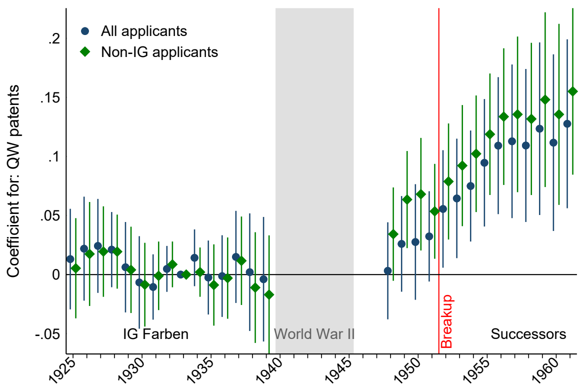
Notes: Technology-year panel linear regression (untransformed dependent variable) with 95% confidence intervals. Regressions comparing technology classes by their exposure to the IG Farben breakup, as defined as $D_i = log(\Delta\text{HHI})$ with $D_i = 0$ for $\Delta\text{HHI} \leq 1$. Exposure is measured using pre-war (1925-1939) data, but the breakup is finalized and effective around 1952. Shows quality-weighted counts of granted patents, with average patent quality winsorized and rescaled to have average three and standard deviation one to exclude negative values. The German patent office closed from 1945 to 1947. Wartime patent applications are largely prosecuted post-war and hence omitted.

Figure C-4: Event studies: Poisson estimates

(a) Patent count



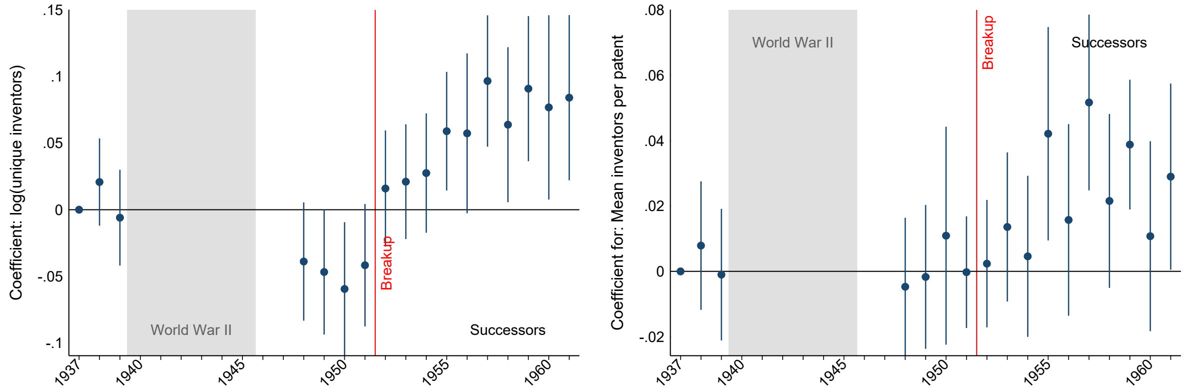
(b) Quality-weighted patents



Notes: Technology-year panel Poisson regression with 95% confidence intervals. Regressions comparing technology classes by their exposure to the IG Farben breakup, as defined as $D_i = log(\Delta\text{HHI})$ with $D_i = 0$ for $\Delta\text{HHI} \leq 1$. Exposure is measured using pre-war (1925-1939) data, but the breakup is finalized and effective around 1952. Shows quality-weighted counts of granted patents, with average patent quality winsorized and rescaled to have average three and standard deviation one to exclude negative values. The German patent office closed from 1945 to 1947. Wartime patent applications are largely prosecuted post-war and hence omitted.

Figure C-5: Regressions based on disambiguated inventors

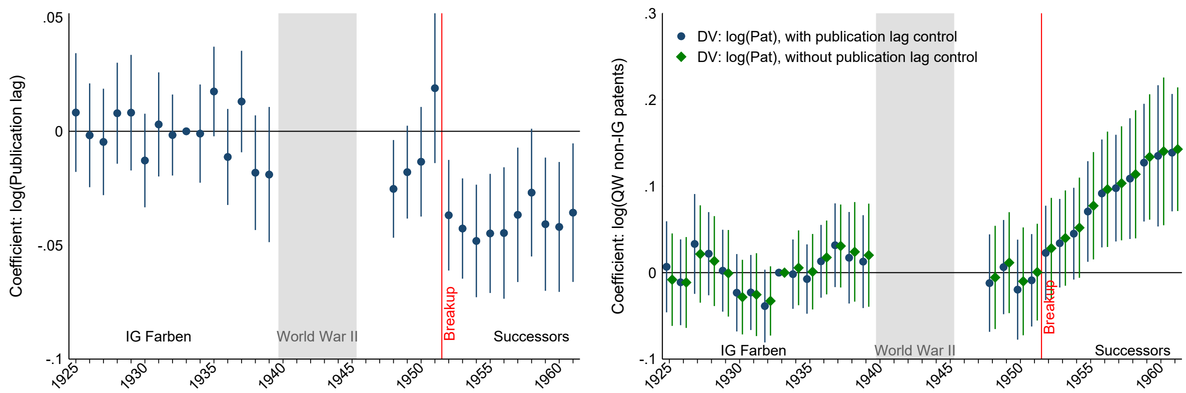
(a) Number of unique inventors (b) Mean inventors per patent



Notes: Technology-year panel regression with 95% confidence intervals. Regressions comparing technology classes by their exposure to the IG Farben breakup, as defined as $D_i = log(\Delta\text{HHI})$ with $D_i = 0$ for $\Delta\text{HHI} \leq 1$. Exposure is measured using pre-war (1925-1939) data, but the breakup is finalized and effective around 1952. The German patent office closed from 1945 to 1947. Wartime patent applications are largely prosecuted post-war and hence omitted. Before 1937, inventor information on German patents is only available for large companies such as IG Farben. See Appendix A.

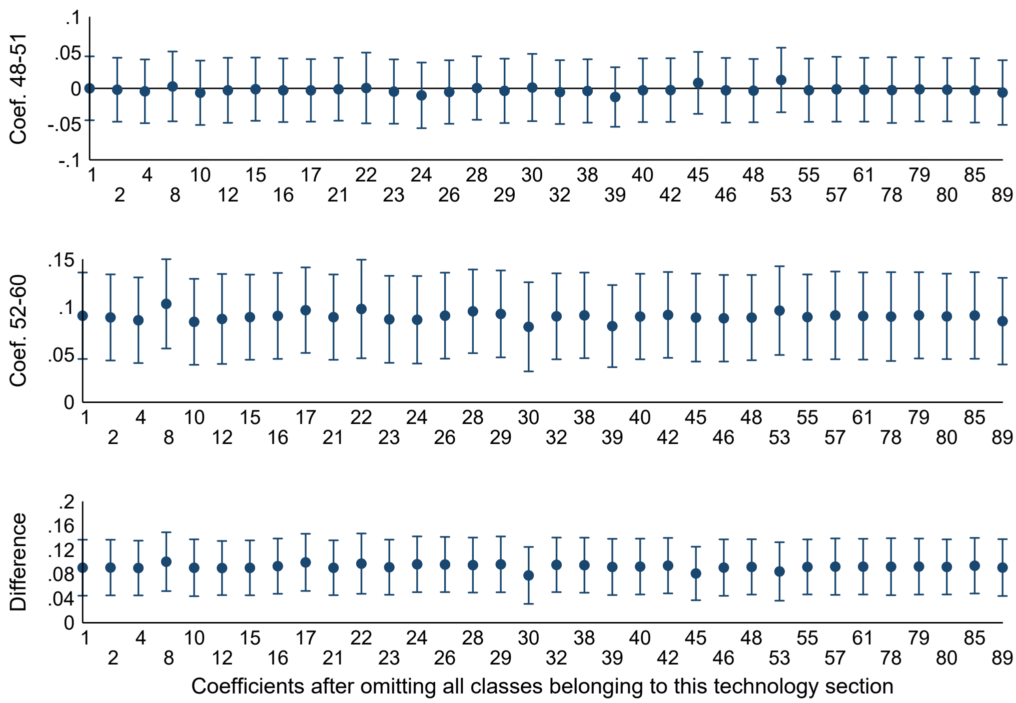
Figure C-6: Regressions involving the publication lag

(a) Publication lag as dependent variable (b) Publication lag as control



Notes: Technology-year panel regression with 95% confidence intervals. In C-6a, the dependent variable is the (log) average publication lag, defined as the difference between grant year and application year for patents filed in a given technology class and year. The publication lag is a measure of the patent prosecution speed. In C-6b, the yearly (log) publication lag is included as a control variable, interacted with year indicators. In both panels, the regressions compare technology classes by their exposure to the IG Farben breakup, as defined as $D_i = log(\Delta\text{HHI})$ with $D_i = 0$ for $\Delta\text{HHI} \leq 1$. Exposure is measured using pre-war (1925-1939) data, but the breakup is finalized and effective around 1952. The German patent office closed from 1945 to 1947. Wartime patent applications are largely prosecuted post-war and hence omitted. See Section A.1 and Figure A-2 in the appendix for more information on publication lags.

Figure C-7: Effects in technology-class level regressions after omitting technology areas



Notes: Shows the results of technology-year panel regression with 95% confidence intervals and one technology area (group of technology classes) left out. Shows that the results are not driven by any individual technology. The dependent variable is the quality-weighted non-IG patent count. The coefficients in turn compare patent counts in 1948-1951 and 1952-1961 with the pre-war period. The main effect is the difference between these two coefficients, shown in the third row. Exposure is measured using pre-war (1925-1939) data, but the breakup is finalized and effective around 1952.

Table C-1: Descriptive statistics for IG/non-IG exposed technology classes: High, low, zero

Comparing 1925-1939 tech classes: High vs low vs zero breakup exposure							
N=33 (H) 70 (L) 32 (Z)	High exp.	Low exp.	Zero exp.	Difference (SE) High vs Low		Difference (SE) High vs Zero	
Granted patents (p.a.)	49.95	61.04	14.88	11.09	(26.40)	-35.07	(11.94)
- Domestic	37.02	44.74	9.85	7.72	(20.78)	-27.17	(9.03)
- Foreign	10.19	11.41	3.58	1.23	(4.02)	-6.60	(2.41)
- Quality-weighted	148.24	181.92	46.15	33.69	(76.64)	-102.09	(35.62)
Matched to firm (%)	0.64	0.36	0.25	-0.27	(0.03)	-0.39	(0.04)
- IG Farben (%)	0.37	0.06	0.01	-0.31	(0.02)	-0.36	(0.03)
- Other (%)	0.26	0.30	0.24	0.04	(0.03)	-0.03	(0.03)
HHI (IG together)	1846.44	278.78	712.33	-1567.66	(215.14)	-1134.10	(440.61)
HHI (IG separate)	620.32	244.52	712.33	-375.79	(73.31)	92.02	(322.05)
ΔHHI	1226.12	34.26	0.00	-1191.87	(154.51)	-1226.12	(229.52)
Domestic East (%)	0.17	0.17	0.21	0.00	(0.02)	0.04	(0.03)
Domestic East/Berlin (%)	0.24	0.31	0.30	0.07	(0.02)	0.05	(0.03)
War destruction (%)	0.33	0.32	0.33	-0.01	(0.01)	-0.00	(0.01)
Dismantle (%)	0.41	0.16	0.08	-0.25	(0.03)	-0.33	(0.03)
Dismantle (No IG, %)	0.09	0.11	0.07	0.02	(0.02)	-0.02	(0.02)

Notes: Shows difference between technology classes with high (above 75th percentile), low, and zero (ΔHHI = 0) breakup exposure. All data refers to patents applied for in 1925-1939. Patents counts are annual. Domestic and foreign patents are identified using inventor locations if available, applicant locations otherwise. Patents are weighted according to forward text similarity divided by backward text similarity, on patent-level normalized to mean three and standard deviation one. The share of matched patents refers to patents matched to the firm dataset described in Section H. HHI is calculated first assuming all IG Farben members to be one entity, then separately according to their post-1952 split-up. The location of patents is first described by the share applied for from the Eastern, Soviet sector. Berlin is handled separately due to its special, divided status. War destructions refers to the share of flats destroyed between 1939 and 1945, weighted by the patent locations in a technology class. Dismantlement on the technology class level is calculated as the share of patents by firms targeted by dismantlement. As the exposed group is strongly selected towards IG Farben patents, it is also shown considering only non-IG firms.

Table C-2: Effects in technology class-level regression (Robustness)

	(1)	(2)	(3)	(4)	(5)	(6)
	Exposure: ΔHHI 1925-1939					
log(Patents)	Default	Excl Plastics	Control Dismantle	Control East	Control Destr	Control All
β_{48-51}	0.006	−0.006	0.006	−0.005	0.008	−0.002
	(0.021)	(0.018)	(0.021)	(0.022)	(0.021)	(0.022)
β_{52-61}	0.091	0.075	0.093	0.093	0.092	0.090
	(0.023)	(0.021)	(0.023)	(0.024)	(0.023)	(0.022)
δ_{48-51}: Dismantle (%)			−0.825			−0.302
			(0.715)			(0.872)
δ_{52-61}: Dismantle (%)			1.781			2.073
			(0.683)			(0.862)
δ_{48-51}: East/Berlin (%)				−1.044		−1.076
				(0.587)		(0.752)
δ_{52-61}: East/Berlin (%)				0.170		−0.509
				(0.571)		(0.779)
δ_{48-51}: Destruction (%)					−0.445	−1.225
					(1.158)	(1.209)
δ_{52-61}: Destruction (%)					−0.305	−0.631
					(1.230)	(1.340)
$\beta_{52-61} - \beta_{48-51}$	0.084	0.082	0.087	0.098	0.084	0.093
	(0.022)	(0.022)	(0.020)	(0.024)	(0.022)	(0.023)
Tech FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Classes	135	132	135	135	134	134
Dep. var. mean	4.041	4.006	4.041	4.041	4.045	4.045
Adj. R-Square	0.789	0.792	0.792	0.789	0.789	0.792
Observations	3730	3648	3730	3730	3724	3724

Notes: Standard errors clustered on the technology class level in parentheses. Dependent variable: quality-weighted non-IG Farben patents. Exposure is $D_i = \log(\Delta\text{HHI}^{+})$, where $D_i = 0$ for $\Delta\text{HHI} \leq 1$. ΔHHI is the difference between technology-level concentration, considering IG Farben as one block or as broken up according to the 1952 successors. Column 2 excludes technology area 39 (classes 39A, 39B and 39C), referring to chemical synthesis plastics and handling of plastics. See also Figure C-7. Column 3 controls for the share of non-IG firms targeted for dismantling. The inclusion of IG Farben in this measure would control directly for the IG Farben share, mechanically highly correlated to the breakup indicator. The more appropriate test for effects of dismantlement is a firm-level regression as described in Section H. Column 4 controls for the share of patents located in East Germany or Berlin. Column 5 controls for war destruction, proxied by the share of destroyed flats in the city of patent inventor or applicant. The number of observations differs as for small technology classes, text similarities and quality scores cannot be calculated. The difference in differences coefficients in turn compare patent counts in 1948-1951 and 1952-1961 with the pre-war period. The main effect is the difference between these two coefficients, tabulated in row {52-61}-{48-51}.

Table C-3: Effects in technology class-level regression (alternative exposure specifications)

	DV: log quality-weighted patent counts of non-IG Farben applicants							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
D_i	$\log(\Delta\text{HHI}^{+})$		$\log(\Delta\text{HHI})$		$\log(\Delta\text{HHI adj})$		$\text{ihs}(\Delta\text{HHI})$	
β_{48-51}	0.006	−0.002	0.014	0.001	0.001	−0.002	0.005	−0.003
	(0.021)	(0.022)	(0.020)	(0.023)	(0.011)	(0.011)	(0.019)	(0.020)
β_{52-61}	0.091	0.090	0.087	0.099	0.038	0.035	0.082	0.081
	(0.023)	(0.022)	(0.025)	(0.023)	(0.011)	(0.011)	(0.021)	(0.021)
β_{52-61}	0.084	0.093	0.073	0.099	0.037	0.037	0.077	0.084
$-\beta_{48-51}$	(0.022)	(0.023)	(0.024)	(0.025)	(0.013)	(0.013)	(0.020)	(0.022)
Tech FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls		Yes		Yes		Yes		Yes
Classes	135	134	103	103	135	134	135	134
DV mean	4.041	4.045	4.229	4.229	4.041	4.045	4.041	4.045
Adj. R^2	0.789	0.792	0.795	0.801	0.786	0.790	0.788	0.792
N	3730	3724	2932	2932	3730	3724	3730	3724

Notes: Standard errors clustered on the technology class level in parentheses. ΔHHI is the difference between technology-level concentration, considering IG Farben as one block or as broken up according to the 1952 successors. ΔHHI is strongly right-skewed, but its logarithm is not. $\log(\Delta\text{HHI}^{+})$ denotes the default specification, where $D_i = 0$ for $\Delta\text{HHI} \leq 1$. $\log(\Delta\text{HHI})$ is the unadjusted log-specification, where technologies with $\Delta\text{HHI} = 0$ drop out. $\log(\Delta\text{HHI adj})$ replaces D_i with the observed minimum where $\Delta\text{HHI} = 0$. $\text{ihs}(\Delta\text{HHI})$ uses the inverse hyperbolic sine transformation. The difference in differences coefficients in turn compare patent counts in 1948-1951 and 1952-1961 with the pre-war period. The main effect is the difference between these two coefficients, $\beta_{52-61} - \beta_{48-51}$. The number of observations differs in columns 2 and 3 for technologies where $\Delta\text{HHI} = 0$.

Table C-4: Effects in technology class-level regression (Extended)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Exposure: ΔHHI 1925-1939								1930-1939	1925-1935	1948-1952
log(Patents)	All (Quality)	All (Quality)	Non-IG (Quality)	Non-IG (Quality)	All (Count)	Non-IG (Count)	Domestic (Quality)	Foreign (Quality)	Non-IG (Quality)	Non-IG (Quality)	Non-IG (Quality)
β_{48-51}	−0.039	−0.043	0.006	−0.002	−0.031	0.002	−0.111	0.072	−0.006	−0.002	0.009
	(0.023)	(0.024)	(0.021)	(0.022)	(0.024)	(0.022)	(0.025)	(0.026)	(0.022)	(0.021)	(0.022)
β_{52-61}	0.064	0.066	0.091	0.090	0.072	0.093	0.020	0.153	0.086	0.085	0.088
	(0.025)	(0.023)	(0.023)	(0.022)	(0.022)	(0.022)	(0.023)	(0.025)	(0.023)	(0.022)	(0.024)
$\beta_{52-61} - \beta_{48-51}$	0.103	0.109	0.084	0.093	0.103	0.090	0.131	0.081	0.091	0.086	0.079
	(0.021)	(0.023)	(0.022)	(0.023)	(0.022)	(0.021)	(0.026)	(0.018)	(0.022)	(0.023)	(0.026)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls		Yes		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Classes	135	134	135	134	134	134	134	134	133	134	133
Dep. var. mean	4.167	4.171	4.041	4.045	3.068	2.942	3.749	3.003	4.051	4.045	4.052
Pseudo R-Square	0.793	0.796	0.789	0.792	0.830	0.828	0.765	0.742	0.792	0.791	0.791
Observations	3757	3751	3730	3724	3766	3739	3690	3364	3715	3724	3715

Notes: Standard errors clustered on the technology class level in parentheses. Exposure is $D_i = \log(\Delta\text{HHI}^{+})$, where $D_i = 0$ for $\Delta\text{HHI} \leq 1$. ΔHHI is the difference between technology-level concentration, considering IG Farben as one block or as broken up according to the 1952 successors. The difference in differences coefficients in turn compare patent counts in 1948-1951 and 1952-1961 with the pre-war period. The main effect is the difference between these two coefficients, tabulated in row {52-61}-{48-51}. The dependent variables are quality-weighted patent counts, except columns (3) and (4) with simple patent counts. Quality weights are normalized to mean three, standard deviation one. The columns restrict patents by applicants, either all (columns 1, 3) or applicants unconnected to IG Farben (columns 2, 4, 7-9). Columns 5-6 restrict patents by location, where inventor location is preferred if available. Domestic patents refer to patents with a German location, foreign patents to patents with a foreign location. Controls include the share of non-IG firms targeted for dismantling, the share of patents located in East Germany or Berlin and war destruction, proxied by the share of destroyed flats in the city of patent inventor or applicant. For details see Section H and Table C-2. The number of observations differs if for some technologies, the ΔHHI or quality scores could not be computed.

Table C-5: Effects in technology class-level regression (Exposure within IG Farben)

Exposure	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Standardized ΔHHI within IG Farben				Standardized ΔHHI by occupation zones			
log(Patents)	All (Quality)	All (Quality)	Non-IG (Quality)	Non-IG (Quality)	All (Quality)	All (Quality)	Non-IG (Quality)	Non-IG (Quality)
β_{48-51}	−0.069	−0.069	−0.026	−0.035	−0.050	−0.054	−0.008	−0.024
	(0.061)	(0.061)	(0.060)	(0.058)	(0.066)	(0.069)	(0.064)	(0.064)
β_{52-61}	0.143	0.148	0.163	0.163	0.180	0.177	0.215	0.205
	(0.061)	(0.061)	(0.061)	(0.062)	(0.064)	(0.060)	(0.064)	(0.061)
$\beta_{52-61} - \beta_{48-51}$	0.211	0.217	0.189	0.197	0.230	0.231	0.223	0.229
	(0.063)	(0.064)	(0.062)	(0.061)	(0.068)	(0.068)	(0.066)	(0.066)
Tech FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls		Yes		Yes		Yes		Yes
Classes	114	114	114	114	114	114	114	114
Dep. var. mean	4.335	4.335	4.191	4.191	4.321	4.321	4.176	4.176
Adj. R-Square	0.790	0.795	0.789	0.793	0.792	0.796	0.791	0.795
Observations	3248	3248	3222	3222	3247	3247	3221	3221

Notes: Standard errors clustered on the technology class level in parentheses. $\Delta\mathrm{HHI}_{\mathrm{Within}}$ is the difference between technology-level concentration among IG Farben-related patents, considering IG Farben as one block or as broken up according to the 1952 successors. $\Delta\mathrm{HHI}_{\mathrm{Occ}}$ breaks up the IG Farben block by occupation zones, ignoring subsidiary structures. In both cases, patents from the Soviet occupation zone are ignored, see Section 4.2 for details. Both ΔHHI are standardized to mean zero and standard deviation one. The difference in differences coefficients in turn compare patent counts in 1948-1951 and 1952-1961 with the pre-war period. The main effect is the difference between these two coefficients, tabulated in row {52-61}-{48-51}. Columns 1-2 and 5-6 count all patents, columns 3-4 and 7-8 only non-IG patents. Controls include the share of non-IG firms targeted for dismantling, the share of patents located in East Germany or Berlin and war destruction, proxied by the share of destroyed flats in the city of patent inventor or applicant. For details see Section H and Table C-2. For dynamic estimates, see Figure 6.

Table C-6: Effects in technology class-level regression (Poisson)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Exposure: ΔHHI 1925-1939								1930-1939	1925-1935	1948-1952
Poisson(Patents)	All (Quality)	All (Quality)	Non-IG (Quality)	Non-IG (Quality)	All (Count)	Non-IG (Count)	Domestic (Quality)	Foreign (Quality)	Non-IG (Quality)	Non-IG (Quality)	Non-IG (Quality)
β_{48-51}	0.018	0.003	0.055	0.035	0.016	0.044	−0.078	0.152	0.033	0.034	0.039
	(0.017)	(0.020)	(0.018)	(0.022)	(0.021)	(0.023)	(0.021)	(0.027)	(0.022)	(0.021)	(0.023)
β_{52-61}	0.094	0.133	0.122	0.158	0.135	0.158	0.076	0.210	0.157	0.154	0.168
	(0.023)	(0.022)	(0.025)	(0.023)	(0.023)	(0.024)	(0.021)	(0.030)	(0.023)	(0.023)	(0.025)
$\beta_{52-61} - \beta_{48-51}$	0.075	0.130	0.067	0.124	0.119	0.114	0.154	0.058	0.124	0.120	0.128
	(0.021)	(0.018)	(0.022)	(0.019)	(0.017)	(0.017)	(0.020)	(0.021)	(0.019)	(0.019)	(0.019)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls		Yes		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Classes	135	134	135	134	134	134	134	134	133	134	133
Dep. var. mean	162.808	163.312	143.153	143.595	52.917	46.468	106.389	47.345	144.191	143.595	144.077
Pseudo R-Square	0.914	0.919	0.915	0.919	0.902	0.901	0.908	0.873	0.919	0.919	0.919
Observations	3792	3780	3792	3780	3886	3886	3780	3780	3764	3780	3767

Notes: Standard errors clustered on the technology class level in parentheses. Exposure is $D_i = \log(\Delta\text{HHI}^+)$, where $D_i = 0$ for $\Delta\text{HHI} \leq 1$. ΔHHI is the difference between technology-level concentration, considering IG Farben as one block or as broken up according to the 1952 successors. The difference in differences coefficients in turn compare patent counts in 1948-1951 and 1952-1961 with the pre-war period. The main effect is the difference between these two coefficients, tabulated in row {52-61}-{48-51}. The dependent variables are quality-weighted patent counts, except columns (3) and (4) with simple patent counts. Quality weights are normalized to mean three, standard deviation one. The columns restrict patents by applicants, either all (columns 1, 3) or applicants unconnected to IG Farben (columns 2, 4, 7-9). Columns 5-6 restrict patents by location, where inventor location is preferred if available. Domestic patents refer to patents with a German location, foreign patents to patents with a foreign location. Controls include the share of non-IG firms targeted for dismantling, the share of patents located in East Germany or Berlin and war destruction, proxied by the share of destroyed flats in the city of patent inventor or applicant. For details see Section H and Table C-2. The number of observations differs if for some technologies, the ΔHHI or quality scores could not be computed.

Table C-7: Effects in technology class-level regression (Robustness)

	(1)	(2)	(3)
	Exposure: ΔHHI 1925-1939		
log(Patents)	Uncontrolled	Controlled	Oster
48-51× High ΔHHI	−0.05	−0.11	−0.14
52-61× High ΔHHI	0.43	0.41	0.40
{52-61}-{48-51}	0.48	0.52	0.54

Notes: Shows coefficients from regression with and without controls as well as resulting Oster (2019) bounds. Dependent variable: quality-weighted non-IG Farben patents. Exposure is $D_i = \log(\Delta\text{HHI}^{+})$, where $D_i = 0$ for $\Delta\text{HHI} \leq 1$. ΔHHI is the difference between technology-level concentration, considering IG Farben as one block or as broken up according to the 1952 successors. Controls are the share of non-IG firms targeted for dismantling, the share of patents located in East Germany or Berlin as well as war destruction, proxied by the share of destroyed flats in the city of patent inventor or applicant. Control variables are interacted with a full set of year indicators. The difference in differences coefficients in turn compare patent counts in 1948-1951 and 1952-1961 with the pre-war period. The main effect is the difference between these two coefficients, tabulated in row {52-61}-{48-51}. Bounds are calculated as: $\beta^{*} = \tilde{\beta} - [\dot{\beta} - \tilde{\beta}] \frac{R_{max} - \tilde{R}}{\tilde{R} - \dot{R}}$, where $\dot{\beta}$ and $\dot{R}$ refer the uncontrolled coefficient and R-Squared and $\tilde{\beta}$ and $\tilde{R}$ to the controlled coefficient and R-Squared. R_{max} is set to $1.3 \times \tilde{R}$. The underlying assumption is that reaction of coefficients to observable controls informs about the potential importance of omitted variable bias.

Table C-8: Effects in technology class-level regression: Separating untreated classes

	(1)	(2)	(3)	(4)
	Exposure: Categories of ΔHHI 1925-1939			
log(Patents)	Non-IG (Quality)	Non-IG (Quality)	Non-IG (Quality)	Non-IG (Quality)
β^{low}_{48-51}	0.003			0.016
	(0.138)			(0.138)
β^{low}_{52-61}	0.088			0.105
	(0.133)			(0.133)
β^{high}_{48-51}	−0.112	−0.122	−0.160	
	(0.171)	(0.133)	(0.176)	
β^{high}_{52-61}	0.470	0.381	0.437	
	(0.181)	(0.164)	(0.187)	
$\beta^{low}_{52-61} - \beta^{low}_{48-51}$	0.085			0.089
	(0.163)			(0.163)
$\beta^{high}_{52-61} - \beta^{high}_{48-51}$	0.582	0.503	0.597	
	(0.193)	(0.143)	(0.192)	
Excluded		ΔHHI = 0	Low ΔHHI	High ΔHHI
Tech FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Classes	134	103	64	101
Dep. var. mean	4.045	4.229	3.717	4.052
Adj. R-Square	0.790	0.797	0.754	0.796
Observations	3724	2932	1713	2803

Notes: Standard errors clustered on the technology class level in parentheses. ΔHHI is the difference between technology-level concentration, considering IG Farben as one block or as broken up according to the 1952 successors. Exposure is split into categories, separating high treatment (top 75th percentile, 33 classes), low treatment (72 classes), and no treatment (ΔHHI = 0, 30 classes). No treatment is the baseline group. The difference in differences coefficients in turn compare patent counts in 1948-1951 and 1952-1961 with the pre-war period. The main effect is the difference between these two coefficients, tabulated in row {52-61}-{48-51}. The dependent variables are quality-weighted patent counts of applicants unconnected to IG Farben, where quality weights are normalized to mean three, standard deviation one.

Table C-9: Effects in technology class-level regression: Alternative samples

log(Patents)	(1) Non-IG (Count)	(2) Non-IG (Count)	(3) Non-IG (Count)	(4) Non-IG (Count)	(5) Non-IG (Count)	(6) Non-IG (Count)
	Exposure: ΔHHI 1925-1939					
β_{48-51}	0.002	0.004	0.005	−0.013	−0.004	−0.028
	(0.022)	(0.015)	(0.031)	(0.017)	(0.022)	(0.027)
β_{52-61}	0.093	0.089	0.115	0.066	0.088	0.057
	(0.022)	(0.017)	(0.031)	(0.019)	(0.023)	(0.030)
$\beta^{low}_{52-61} - \beta^{low}_{48-51}$	0.090	0.084	0.110	0.079	0.091	0.085
	(0.021)	(0.014)	(0.028)	(0.019)	(0.022)	(0.023)
Sample	Chemistry	All tech	10+ IG Pat	Baten 2017	Prod. 20%	Prod. 50%
Tech FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Classes	134	502	86	193	128	98
Dep. var. mean	2.942	2.919	3.245	3.100	2.933	2.791
Adj. R-Square	0.828	0.811	0.832	0.833	0.826	0.800
Observations	3739	13787	2454	5449	3565	2736

Notes: Standard errors clustered on the technology class level in parentheses. ΔHHI is the difference between technology-level concentration, considering IG Farben as one block or as broken up according to the 1952 successors. Dependent variable: non-IG Farben patent counts (for computational reasons, quality weights are not computed for classes outside chemistry). Exposure is $D_i = \log(\Delta\text{HHI}^+)$, where $D_i = 0$ for $\Delta\text{HHI} \leq 1$. ΔHHI is the difference between technology-level concentration, considering IG Farben as one block or as broken up according to the 1952 successors. The difference in differences coefficients in turn compare patent counts in 1948-1951 and 1952-1961 with the pre-war period. The main effect is the difference between these two coefficients, tabulated in row {52-61}-{48-51}. The columns display results for the default sample within chemistry (column 1), for all technologies (column 2), technologies with at least 10 pre-war IG Farben patents (column 3), chemistry as defined in Baten, Bianchi, and Moser, 2017 (column 4) and technologies with at least 20% or 50% of patents mentioning chemical products (columns 5 and 6).

Table C-10: Effects in technology class-level regression: Duplication

	All patents				Non-IG Farben patents			
	(1) Patent count	(2) Excl. high sim.	(3) Qual. weight	(4) Excl. high sim.	(5) Patent count	(6) Excl. high sim.	(7) Qual. weight	(8) Excl. high sim.
β_{48-51}	−0.025	−0.010	0.008	0.009	−0.039	−0.024	0.002	0.002
	(0.024)	(0.024)	(0.022)	(0.023)	(0.025)	(0.025)	(0.023)	(0.024)
β_{52-61}	0.070	0.076	0.091	0.089	0.063	0.069	0.088	0.087
	(0.024)	(0.023)	(0.023)	(0.023)	(0.024)	(0.023)	(0.024)	(0.024)
$\beta_{52-61} - \beta_{48-51}$	0.095	0.087	0.083	0.081	0.102	0.093	0.086	0.084
	(0.022)	(0.022)	(0.022)	(0.021)	(0.024)	(0.023)	(0.023)	(0.023)
Tech, Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Classes	134	134	134	134	134	134	134	134
Dep. var. mean	3.068	2.817	2.942	2.709	4.171	3.927	4.045	3.817
Adj. R-Square	0.830	0.823	0.829	0.822	0.796	0.787	0.792	0.783
Observations	3766	3751	3739	3722	3751	3736	3724	3707

Notes: Standard errors clustered on the technology class level in parentheses. The dependent variables are simple (columns 1-2, 5-6) or quality-weighted (columns 3-4, 7-8) patent counts. Columns 2, 4, 6 and 8 exclude patents which are highly similar to another patent in the last five years in the same technology, with similarity threshold benchmarked by the similarity of patents of addition as discussed in the main text. The columns further restrict patents by applicants, either all (columns 1-4) or applicants unconnected to IG Farben (columns 5-8). ΔHHI is the difference between technology-level concentration, considering IG Farben as one block or as broken up according to the 1952 successors. Exposure is set to zero for $\Delta\text{HHI} \leq 1$. The difference in differences coefficients in turn compare patent counts in 1948-1951 and 1952-1961 with the pre-war period. The main effect is the difference between these two coefficients, tabulated in row {52-61}-{48-51}. For control variables, see Table C-2.

Table C-11: Technology-level regressions with product market exposure

	Exposure: Product mentions in patents			
	(1)	(2)	(3)	(4)
log(Patents)	Non-IG (Quality)	Non-IG (Quality)	Non-IG (Count)	Non-IG (Count)
$\beta_{48-51}^{2+\text{ IG Successors}}$	0.405	0.309	0.353	0.216
	(0.318)	(0.348)	(0.307)	(0.324)
$\beta_{52-61}^{2+\text{ IG Successors}}$	0.976	0.979	0.922	0.868
	(0.421)	(0.443)	(0.416)	(0.437)
$\beta_{48-51}^{1\text{ IG Successor}}$	−0.049	0.190	0.184	0.319
	(0.442)	(0.456)	(0.370)	(0.389)
$\beta_{52-61}^{1\text{ IG Successor}}$	2.251	2.037	2.372	2.205
	(0.478)	(0.506)	(0.469)	(0.499)
$\beta_{52-61}^{2+\text{ IG Successors}} - \beta_{48-51}^{2+\text{ IG Successors}}$	0.571	0.671	0.569	0.652
	(0.372)	(0.427)	(0.342)	(0.406)
$\beta_{52-61}^{1\text{ IG Successor}} - \beta_{48-51}^{1\text{ IG Successor}}$	2.300	1.847	2.188	1.887
	(0.522)	(0.536)	(0.470)	(0.488)
Tech, Year FE	Yes	Yes	Yes	Yes
Controls		Yes		Yes
Classes	135	134	135	134
Dep. var. mean	4.041	4.045	2.935	2.942
Adj. R-Square	0.792	0.794	0.831	0.831
Observations	3730	3724	3750	3739

Notes: Standard errors clustered on the technology level in parentheses. The dependent variables are log (quality-weighted) patents in technology classes related to the chemical industry by non-IG Farben firms. Product market exposure is the (weighted) share of patents mentioning a chemical with post-breakup competition (for $\beta^{2+\text{IG}}$, $\sigma_{Exp}^{2+\text{IG}} = 0.11$) or only one post-breakup successor (for $\beta^{1\text{ IG}}$, $\sigma_{Exp}^{1\text{ IG}} = 0.16$). For control variables, see the legend of Table E-2 in the appendix (column 7).

D Supplementary results: Innovation Analysis in Product Panel

Table D-1: Product-level regressions

	Exposure: Product-level competition					
	(1)	(2)	(3)	(4)	(5)	(6)
Patents (Quality-weighted)	All	All	IG	IG	Non-IG	Non-IG
$\beta_{48-51}^{2+\text{ IG Successors}}$	0.115	0.129	0.148	0.135	0.164	0.182
	(0.056)	(0.061)	(0.095)	(0.100)	(0.055)	(0.061)
$\beta_{52-61}^{2+\text{ IG Successors}}$	0.223	0.244	0.109	0.101	0.277	0.304
	(0.093)	(0.098)	(0.127)	(0.130)	(0.094)	(0.099)
$\beta_{48-51}^{1\text{ IG Successor}}$	0.055	0.052	0.092	0.054	0.044	0.043
	(0.057)	(0.058)	(0.079)	(0.084)	(0.069)	(0.069)
$\beta_{52-61}^{1\text{ IG Successor}}$	0.099	0.086	0.181	0.146	0.081	0.067
	(0.105)	(0.103)	(0.121)	(0.122)	(0.115)	(0.113)
$\beta_{52-61}^{2+\text{ IG Successors}} - \beta_{48-51}^{2+\text{ IG Successors}}$	0.108	0.114	−0.038	−0.033	0.114	0.122
	(0.059)	(0.060)	(0.085)	(0.083)	(0.061)	(0.063)
$\beta_{52-61}^{1\text{ IG Successor}} - \beta_{48-51}^{1\text{ IG Successor}}$	0.044	0.035	0.088	0.092	0.038	0.024
	(0.075)	(0.075)	(0.101)	(0.098)	(0.070)	(0.071)
Product, Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls		Yes		Yes		Yes
Products	1084	1084	1012	1012	1084	1084
Dep. var. mean	14.416	14.416	2.739	2.739	11.751	11.751
Pseudo R-Square	0.880	0.880	0.748	0.749	0.874	0.874
Observations	25561	25561	24867	24867	25561	25561

Notes: Standard errors clustered on the product level in parentheses. The dependent variables are patent quality-weighted and mentioning frequency-weighted counts of patents mentioning products. Estimated using Poisson regression. Product market exposure indicates whether a product experienced with post-breakup competition between IG Farben successors (for $\beta^{2+\text{ IG}}$) or only one post-breakup successor was present (for $\beta^{1\text{ IG}}$). For results without quality-weighting, see Table D-2 in the appendix. Includes all products, for results excluding product categories, see Table D-3 in the appendix. Controls include the share of suppliers in the 1939 product catalog that were located in East Germany or Berlin, that were a cartel, or that were on an Allied dismantlement list. For 1952 products not matched in 1939, the control variables are set to zero.

Table D-2: Product-level regressions: No quality weighting, all products

	Exposure: Product-level competition					
	(1)	(2)	(3)	(4)	(5)	(6)
Patents	All	All	IG	IG	Non-IG	Non-IG
$\beta_{48-51}^{2+\text{ IG Successors}}$	0.135	0.149	0.159	0.144	0.175	0.194
	(0.056)	(0.061)	(0.103)	(0.107)	(0.054)	(0.059)
$\beta_{52-61}^{2+\text{ IG Successors}}$	0.233	0.252	0.126	0.115	0.280	0.307
	(0.089)	(0.093)	(0.123)	(0.126)	(0.089)	(0.095)
$\beta_{48-51}^{1\text{ IG Successor}}$	0.062	0.056	0.089	0.046	0.052	0.049
	(0.055)	(0.057)	(0.084)	(0.090)	(0.066)	(0.066)
$\beta_{52-61}^{1\text{ IG Successor}}$	0.103	0.089	0.173	0.137	0.088	0.072
	(0.098)	(0.098)	(0.115)	(0.117)	(0.106)	(0.105)
$\beta_{52-61}^{2+\text{ IG Successors}} - \beta_{48-51}^{2+\text{ IG Successors}}$	0.098	0.104	−0.033	−0.029	0.105	0.113
	(0.054)	(0.054)	(0.076)	(0.074)	(0.056)	(0.057)
$\beta_{52-61}^{1\text{ IG Successor}} - \beta_{48-51}^{1\text{ IG Successor}}$	0.041	0.034	0.084	0.091	0.036	0.023
	(0.066)	(0.066)	(0.090)	(0.089)	(0.061)	(0.063)
Product, Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls		Yes		Yes		Yes
Products	1084	1084	1012	1012	1084	1084
Dep. var. mean	4.794	4.794	0.925	0.925	3.895	3.895
Pseudo R-Square	0.826	0.826	0.664	0.665	0.819	0.820
Observations	25561	25561	24867	24867	25561	25561

Notes: Standard errors clustered on the product level in parentheses. The dependent variables are frequency-weighted counts of patents mentioning products. Product market exposure indicates whether a product experienced with post-breakup competition between IG Farben successors (for $\beta^{2+\text{IG}}$) or only one post-breakup successor was present (for $\beta^{1\text{ IG}}$). Controls include the share of suppliers in the 1939 product catalog that were located in East Germany or Berlin, that were a cartel, or that were on an Allied dismantlement list. For 1952 products not matched in 1939, the control variables are set to zero.

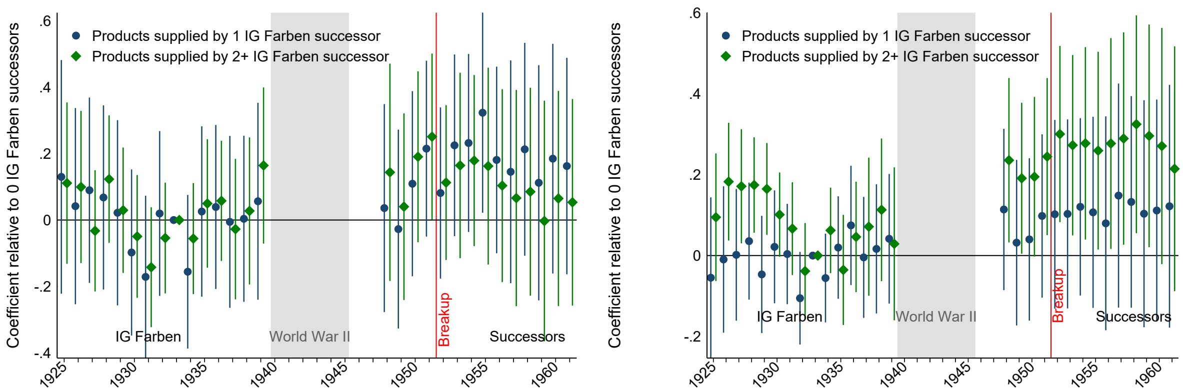
Table D-3: Product-level regressions: Excluding product categories

	Exposure: Product-level competition					
	(1)	(2)	(3)	(4)	(5)	(6)
Patents (Quality-weighted)	All	All	IG	IG	Non-IG	Non-IG
$\beta_{48-51}^{2+\text{ IG Successors}}$	0.083	0.104	0.152	0.152	0.131	0.158
	(0.064)	(0.073)	(0.099)	(0.105)	(0.065)	(0.077)
$\beta_{52-61}^{2+\text{ IG Successors}}$	0.142	0.180	0.073	0.079	0.195	0.244
	(0.106)	(0.118)	(0.130)	(0.135)	(0.111)	(0.126)
$\beta_{48-51}^{1\text{ IG Successor}}$	0.059	0.058	0.102	0.064	0.070	0.080
	(0.075)	(0.075)	(0.083)	(0.088)	(0.091)	(0.088)
$\beta_{52-61}^{1\text{ IG Successor}}$	0.122	0.119	0.182	0.148	0.117	0.125
	(0.120)	(0.118)	(0.124)	(0.124)	(0.135)	(0.128)
$\beta_{52-61}^{2+\text{ IG Successors}} - \beta_{48-51}^{2+\text{ IG Successors}}$	0.059	0.076	−0.079	−0.073	0.064	0.086
	(0.067)	(0.070)	(0.084)	(0.083)	(0.072)	(0.075)
$\beta_{52-61}^{1\text{ IG Successor}} - \beta_{48-51}^{1\text{ IG Successor}}$	0.064	0.061	0.080	0.084	0.047	0.045
	(0.078)	(0.078)	(0.100)	(0.097)	(0.079)	(0.080)
Product, Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls		Yes		Yes		Yes
Products	915	915	865	865	915	915
Dep. var. mean	14.755	14.755	3.133	3.133	11.681	11.681
Pseudo R-Square	0.875	0.876	0.757	0.758	0.865	0.865
Observations	21770	21770	21356	21356	21770	21770

Notes: Standard errors clustered on the product level in parentheses. The dependent variables are patent quality-weighted and mentioning frequency-weighted counts of patents mentioning products. Product categories are excluded both when calculating frequency-weighted counts and from the panel. Product market exposure indicates whether a product experienced with post-breakup competition between IG Farben successors (for $\beta^{2+\text{IG}}$) or only one post-breakup successor was present (for $\beta^{1\text{ IG}}$). Controls include the share of suppliers in the 1939 product catalog that were located in East Germany or Berlin, that were a cartel, or that were on an Allied dismantlement list. For 1952 products not matched in 1939, the control variables are set to zero.

Figure D-1: Product-level regressions: Excluding product categories

(a) Regression analysis: IG Farben patents (b) Regression analysis: Non-IG Farben patents



Notes: Shows annual results following Table D-3. The dependent variables are patent quality-weighted and mentioning frequency-weighted counts of patents mentioning products. Product categories are excluded both when calculating frequency-weighted counts and from the panel. Product market exposure indicates whether a product experienced with post-breakup competition between IG Farben successors (for $\beta^{2+\mathrm{IG}}$) or only one post-breakup successor was present (for $\beta^{1\,\mathrm{IG}}$). For analyses including all products, see Figure D-1.

E Innovation Analysis in Firm Panel

Robustness analysis can be conducted at varying levels. Some variables directly apply to the product level (cartels, production restrictions), and tests for their relevance can be best implemented in product-level regressions that are beyond the scope of this paper and are discussed in Poege (2022). Some variables can be collected and aggregated to a technology class level (war destruction, dismantlement, Soviet sector). Such analysis is bound to remain indirect as the shocks affect firms, not technologies. In a firm-level analysis, measurement and control are more direct. In this section, I construct a firm panel to offer an additional robustness check for the innovation analysis, leading to comparable results.

Building a firm panel To construct the firm panel, I combine various firm data sources. These are supplier lists from historical product catalogs, handbooks of listed corporations (Hoppenstedt-Aktienführer, via https://digi.bib.uni-mannheim.de/aktienfuehrer/), firms slated for dismantlement (Harmssen, 1951), and manually collected complementary entries. I first match the firm entries with each other, and then match the resulting clusters to patent applicants. Appendix A discusses details. The subsequent regressions consider patents in classes relevant to the chemical industry. I focus on incumbent firms for whom exposure measures to the IG Farben breakup and other shocks can be calculated with pre-war variables. I keep only firms with patent applications in at least four pre-war (1925-1939) years. Overall, more than 350 firms remain. The pre-1945 patent count of the eventual IG Farben successors follows the hypothetical reassignment according to the breakup rules.

I calculate the technological exposure of firms to the IG Farben breakup. For this, I weigh the technology class-specific exposure (ΔHHI) by the pre-war patent portfolio of the firms. Table E-1 tabulates the main firm characteristics, separated between highly exposed firms in the top 25% by exposure (Threshold 329) and comparison firms. Both groups have similar pre-war levels of patenting and are similarly exposed to the Soviet sector and to the war destruction of German cities. Exposed firms are moderately more likely to be foreign (as measured by patent locations) but substantially less likely to be a target of dismantlement.

Firm-level results Table E-2 shows the regression results. The empirical strategy follows the main innovation analysis, with the level of observation shifted to firms. I include firm and year fixed effects and cluster standard errors in the regressions at the firm level (Bertrand, Duflo, and Mullainathan, 2004). Compared to comparison firms, firms in technologies with high exposure to the IG Farben breakup strongly increased their patenting output after the breakup. Columns 1-4 individually include the main control variables, and columns 5-7 include them all

Table E-1: Descriptive statistics for IG/non-IG exposed firms

Comparing firms: High vs low breakup exposure					
N=96 (T) 289 (C)	Exposed	Comparison	Difference	(SE)	p-value
Weighted ΔHHI	793.45	61.40	−732.05	(26.00)	0.000
Quality-weighted patents	192.18	279.94	87.76	(152.64)	0.566
- (log)	4.45	4.32	−0.13	(0.15)	0.372
Foreign (%)	0.19	0.10	−0.08	(0.04)	0.032
Pre-war US patent ratio (%)	0.28	0.15	−0.13	(0.03)	0.000
Patents in Soviet sector (%)	0.36	0.38	0.02	(0.05)	0.681
War destruction (%)	0.28	0.29	0.01	(0.02)	0.629
Any plants dismantled (%)	0.13	0.30	0.18	(0.05)	0.000
IG competitor (1940 catalogue)	0.68	0.21	−0.46	(0.05)	0.000
IG competitor (1952 catalogue)	0.59	0.28	−0.32	(0.05)	0.000
IG competitor (Any catalogue)	0.77	0.37	−0.40	(0.06)	0.000

Notes: Shows difference between firms with high and low breakup exposure. All data refers to patents applied for in 1925-1939. The shock exposure ΔHHI for technology classes is calculated first assuming all IG Farben members to be one entity, then separately according to their post-1952 split-up. A firm's value of shock exposure is weighted according to pre-war patent counts in the respective technology classes. Patents counts are totals. Patents are weighted according to forward text similarity divided by backward text similarity, on patent-level normalized to mean three and standard deviation one. Firm locations follow the predominant patent location, where domestic and foreign patents are identified using inventor locations if available, applicant locations otherwise. Domestic are such located in present-day Germany or Poland, Soviet sector patents all located in present-day East Germany, Berlin or Poland. The inclusion of Poland is a coarse reference to Germany's pre-war territory. The pre-war US patent ratio divides the 1925-1939 US patent count of the firm by the 1925-1939 German patent count. For non-German firms this variable typically takes values much larger than one and are winsorized there. War destructions refers to the share of flats destroyed between 1939 and 1945, weighted by the patent locations of a firm. Dismantlement is an indicator for whether the firm occurs in any dismantlement list.

at the same time. Dismantlement, exposure to the Soviet sector, and war destructions predict decreases in patenting in the post-war periods, but the main effect estimates remain unchanged. The effects also remain qualitatively unchanged when excluding IG Farben firms (columns 1-5), when excluding foreign firms (column 6), or considering all firms, including the IG Farben successors (columns 7-8). The results are smaller in magnitude than the technology-class level regressions of Section 6, hinting towards entry by new innovators playing a role.

Table E-2: Firm-level regressions with control variables

	Exposure: log ΔHHI 1925-1939							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ihs(Patents)	No IG	No IG	No IG	No IG	No IG	Domestic	All	All
β_{48-51}	0.002	−0.008	0.005	0.002	0.004	−0.034	−0.006	−0.016
	(0.024)	(0.025)	(0.023)	(0.024)	(0.023)	(0.019)	(0.021)	(0.021)
β_{52-61}	0.057	0.041	0.060	0.056	0.053	0.018	0.053	0.034
	(0.027)	(0.028)	(0.026)	(0.027)	(0.026)	(0.021)	(0.024)	(0.022)
δ_{48-51}: Dismantle		−0.255			−0.016	0.009	−0.041	0.024
		(0.125)			(0.112)	(0.107)	(0.107)	(0.107)
δ_{52-61}: Dismantle		−0.399			−0.127	−0.009	−0.123	0.001
		(0.125)			(0.120)	(0.110)	(0.112)	(0.110)
δ_{48-51}: East			−1.136		−1.176	−0.962	−1.144	−1.022
			(0.120)		(0.123)	(0.118)	(0.120)	(0.121)
δ_{52-61}: East			−1.216		−1.282	−0.820	−1.258	−1.023
			(0.137)		(0.144)	(0.127)	(0.140)	(0.132)
δ_{48-51}: Destruction				−0.142	−0.576	−0.129	−0.558	−0.212
				(0.375)	(0.341)	(0.309)	(0.338)	(0.325)
δ_{52-61}: Destruction				−0.757	−1.221	−0.073	−1.223	−0.560
				(0.411)	(0.378)	(0.283)	(0.374)	(0.306)
δ_{48-51}: Pre-war US								0.992
								(0.228)
δ_{52-61}: Pre-war US								1.903
								(0.238)
$\beta_{52-61} - \beta_{48-51}$	0.055	0.049	0.055	0.054	0.050	0.051	0.059	0.050
	(0.019)	(0.020)	(0.019)	(0.019)	(0.020)	(0.020)	(0.019)	(0.019)
Firm, Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N Firms	384	384	384	384	384	353	402	402
Adj. R-Square	0.550	0.552	0.570	0.552	0.574	0.632	0.611	0.627
Observations	13056	13056	13056	13056	13056	12002	13668	13668

Notes: Standard errors clustered on the firm level in parentheses. The dependent variables are inverse hyperbolic sine transformed quality-weighted patents in technology classes related to the chemical industry. In columns 1-5, the sample consists of firms not related to IG Farben. In column 6, all firms are included and column 7 excludes foreign firms. Exposure is the (log) average ΔHHI, weighted according to the pre-war patent portfolio of a given company. Dismantle is a dummy of whether the firm was featured on a dismantlement list. East Pat is the share of pre-war patents in East Germany or Berlin. Destruction is the average war destruction in the German cities, weighted by pre-war patent locations. Pre-war US is the ratio of 1925-1939 US patent count of the firm, divided by the 1925-1939 German patent count. Poisson regressions or regressions without quality-weighting deliver qualitatively similar results.

Table E-3: Firm-level regressions, accounting for IG Farben inventors

	Exposure: log ΔHHI 1925-1939							
ihs(Patents)	(1) All	(2) All	(3) Excl. IG Inv	(4) Excl. IG Inv	(5) IG Inv only	(6) IG Inv only	(7) IG Inv (bin)	(8) IG Inv (bin)
β_{48-51}	0.002	0.004	0.002	0.003	0.005	0.007	0.002	0.003
	(0.024)	(0.023)	(0.024)	(0.023)	(0.009)	(0.011)	(0.004)	(0.004)
β_{52-61}	0.057	0.053	0.056	0.052	0.006	0.004	0.004	0.004
	(0.027)	(0.026)	(0.027)	(0.026)	(0.007)	(0.008)	(0.003)	(0.004)
$\beta_{52-61} - \beta_{48-51}$	0.055	0.050	0.054	0.049	0.000	−0.002	0.001	0.001
	(0.019)	(0.020)	(0.019)	(0.020)	(0.007)	(0.007)	(0.003)	(0.004)
Firm, Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls		Yes		Yes		Yes		Yes
N Firms	384	384	384	384	384	384	384	384
Adj. R-Square	0.550	0.574	0.551	0.574	0.505	0.509	0.392	0.395
Observations	13056	13056	13056	13056	8448	8448	8448	8448

Notes: Standard errors clustered on the firm level in parentheses. The dependent variables are inverse hyperbolic sine transformed quality-weighted patents in technology classes related to the chemical industry, except in columns 7-8, where binary outcome variables are used. The sample consists of firms not related to IG Farben. Columns 3-4 exclude patents by (former) IG Farben inventors from the patent counts. Columns 5-6 exclusively count patents by (former) IG Farben inventors, and columns 7-8 binarize this measure. Columns 5-8 focuses on years 1937 and after, as inventor are not systematically recorded on patents before. Exposure is the (log) average ΔHHI, weighted according to the pre-war patent portfolio of a given company. Contains controls for dismantlement, east patenting, and destruction. See Table E-2 for details.

Table E-4: Firm-level regressions, exposure to IG Farben inventors

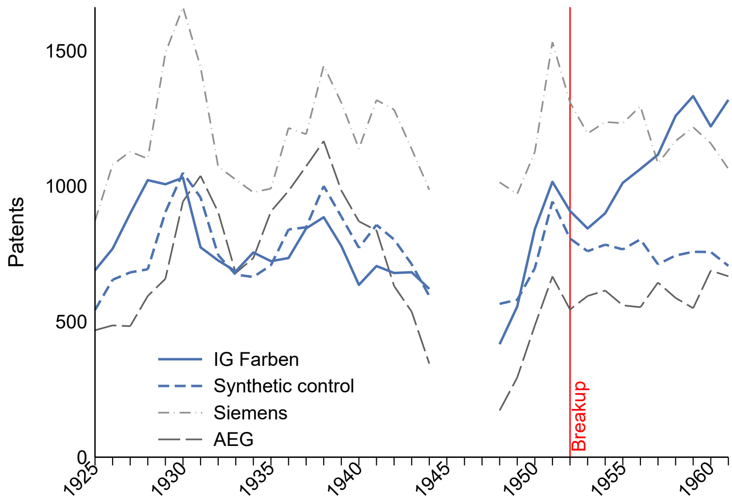
ihs(Patents)		Share 48-51		Share 48-53		Share 52-54	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
β_{48-51}	0.004		0.001		0.000		0.003
	(0.023)		(0.023)		(0.023)		(0.023)
β_{52-61}	0.053		0.052		0.051		0.051
	(0.026)		(0.027)		(0.027)		(0.027)
β^{Inv}_{48-51}		0.893	0.891	0.854	0.854	0.218	0.209
		(0.461)	(0.459)	(0.533)	(0.534)	(0.752)	(0.750)
β^{Inv}_{52-61}		0.527	0.434	0.685	0.536	0.542	0.369
		(0.413)	(0.390)	(0.525)	(0.487)	(0.570)	(0.554)
$\beta_{52-61} - \beta_{48-51}$	0.050		0.051		0.051		0.049
	(0.020)		(0.020)		(0.020)		(0.020)
$\beta_{52-61} - \beta_{48-51}$		−0.365	−0.457	−0.169	−0.318	0.325	0.160
		(0.442)	(0.447)	(0.538)	(0.529)	(0.672)	(0.657)
Firm, Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N Firms	384	384	384	384	384	384	384
Adj. R-Square	0.574	0.573	0.574	0.573	0.574	0.573	0.574
Observations	13056	13056	13056	13056	13056	13056	13056

Notes: Standard errors clustered on the firm level in parentheses. The dependent variables are inverse hyperbolic sine transformed quality-weighted patents in technology classes related to the chemical industry. The sample consists of firms not related to IG Farben. Exposure to inventors of IG Farben is the share of patents by IG Farben inventors in 1948-1951 (1948-1953; 1952-1954), with shares of firms without patents in the corresponding years set to zero. The initial positive effect in 1948-1951 is due to this adjustment, so that the main focus should be on the coefficient difference. Technology-level exposure to IG Farben refers to (log) ΔHHI, pre-war-weighted exposure to ΔHHI in technologies the firm was active in. Contains controls for dismantlement, east patenting, and destruction. See Table E-2 for details.

F Synthetic control for IG Farben

While finding appropriate control firms for IG Farben and its successors is difficult, the best attempt at a descriptive analysis is the comparison with firms in electronics (Feldenkirchen, 1987). The electronics sector was dominated by a duopoly of Siemens and AEG, with some smaller companies like Bosch contributing a smaller share. While Bosch and Siemens were at some point targeted for decartelization measures equivalent to IG Farben, these remained largely without effect. Other candidate sectors drop out as they were also affected by Allied breakups (Heavy industry/Steel) or disproportionately benefited from the war (Automotive engineering). Figure F-1 shows that patenting by IG Farben successors increased relative to AEG, Siemens, or a synthetic control group (Abadie, Diamond, and Hainmueller, 2010) of electronics firms, but this result should be interpreted cautiously.

Figure F-1: IG Farben patenting in comparison to firms in the electronics industry



Notes: Patenting of IG Farben and its successors compared to firms in the electronics industry. Only patents located in West Germany and Berlin are counted. AEG includes Telefunken and Licentia. Siemens includes Siemens & Halske and Siemens Schuckertwerke. Other firms entering the synthetic control are Bosch, C Lorenz/Standard Elektronik Lorenz, Tenovis and Voigt & Haeffner. The synthetic control procedure (Abadie, Diamond, and Hainmueller, 2010) only fits on the 1925-1944 patent counts, resulting in 65% combined weight for AEG and Siemens. A synthetic control using normalized weights yields similar results, with more balanced shares.

G Specialization of Research

Theoretical research on competition, especially mergers, has discussed the role of duplication and breadth of research. Duplication of research between merging companies may be wasteful, and its removal may be a merger efficiency (Denicolò and Polo, 2018). Duplication of research might also be beneficial, especially if the outcomes offer consumers benefits in variety and price - advantages that may be lost after a merger (Letina, 2016; Gilbert, 2019). In this section, I discuss approaches for extending the previous analyses to approach this topic in the context of the IG Farben merger. In the historical context, it is plausible that research in the same technology led to differentiated new products. For example, research in synthetic polymers led to multiple types of plastics with various practical applications.

Empirical research into duplication of research remains scarce because it is difficult to measure outside of individual fields such as pharmaceuticals (Cunningham, Ederer, and Ma, 2021). However, the application of measures of technology and text similarity allows some approximation. In this section, I will approach the topic of overlap by measures of technological similarity derived from technology classes and the text content of words. This falls short of defining duplication, as it is difficult to measure when some patents cover the same technological content. However, some progress is attainable when considering the converse, specialization.

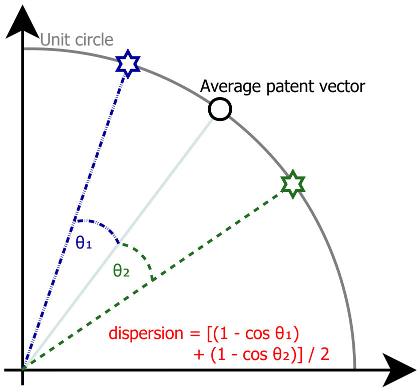
I construct a technology-level measure of the dispersion of technological content, which allows me to return to the empirical strategy of Section 5. Section 7 already presented a descriptive analysis of the technology portfolios of the IG Farben successors, which indicated that they remained active in the same technologies but specialized within them as the pairwise similarity of patent portfolios diverged. While indicative, this finding does not inform about the development of the industry at large. For this, I return to a numerical representation of the technological content of patents. Each patent is again represented by a vector v. Now, I consider the average vector $\bar{v}$ within a set of patents T. Dispersion is given by the average distance - one minus cosine similarity - of all patent vectors v to the average.

$$s = 1/N(T) \sum_{k \in T} (1 - v_k \cdot \bar{v})$$

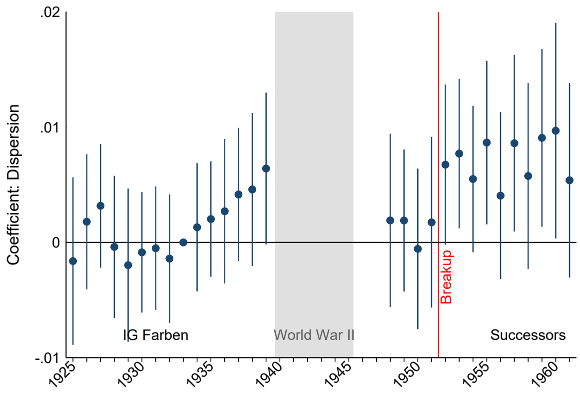
For the empirical test, I calculate the dispersion of yearly patent applications in a technology. I choose T as the set of patents in technology class i and year t. Figure G-1 shows first a graphical illustration and then results. After the breakup, the dispersion increases, indicating a greater average spread of texts within the affected technology classes than before the breakup. At the same time, the number of patents in the affected technologies increases, which suggests that the new patents tend to be farther from the typical patent in the respective technologies.

Figure G-1: Dispersion of technology over time

(a) Visualization: Dispersion



(b) Class-level dispersion of text context

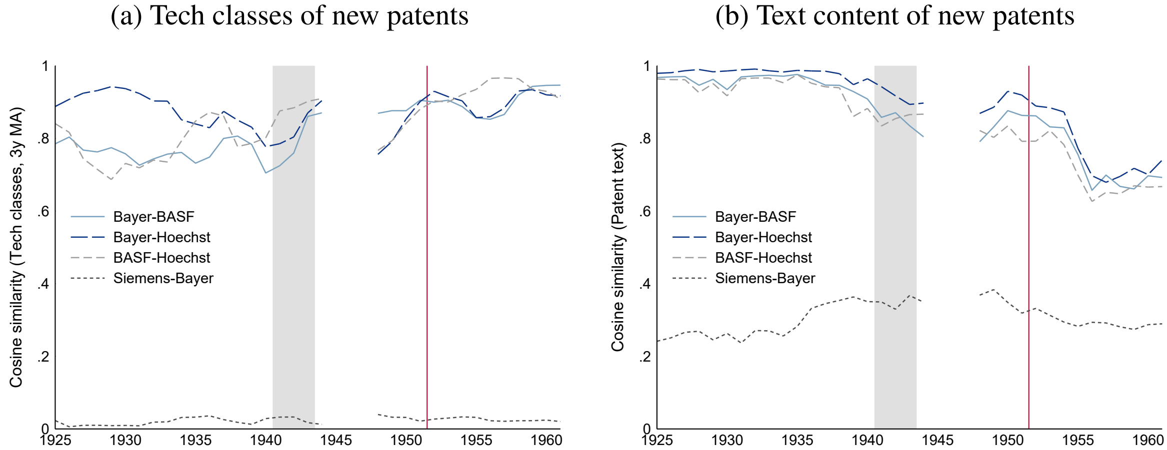


Notes: G-1a: Visualization of dispersion in two-dimensional space and two patents. G-1b: Event study regression with dependent variable dispersion of text content within the technology class, defined as the average cosine distance of patent text vectors from the average patent text vector.

Suppose the reversal of a merger had strongly led to duplication of research. In that case, the average research similarity between successors and the aggregate similarity within technology classes should have stayed the same (same distribution of technology content) or even increased (duplicative marginal patents). The empirically observed decrease points to the diversification of approaches, in line with Letina (2016). The historical evidence indeed points in the same direction. All successors invested in technologies such as plastics, synthetic fibers, or switching from coal to oil as feedstock. However, seeking the same goal in all these technologies led to different approaches and outcomes. Indeed, the explosion of the type of plastics products available to consumers is one of the legacies of chemical research of the 1950s and 1960s (Teltschik, 1992).

Necessarily, this discussion assumes that the assignment of patents to technology classes and the technological disclosure of patents consistently reflects the research investments done at the applicant company. If the breakup changed the drafting style or induced strategic behavior of the successor companies or the non-IG Farben competitors, the measures might overstate changes. However, both research and the patenting process within IG Farben were organized at the plant-level (ter Meer, 1953, p. 30). In the 1930s, all major and several minor plants had a patent office; see Table H-2. Given this, and since any such discussion is absent in the historical literature, the patenting process itself was likely not disturbed by the breakup very much.

Figure G-2: Technology similarity over time: IG Farben successors



Notes: G-2a: Technology similarity between IG Farben successors based on new patents across technology classes. G-2b: Technology similarity between IG Farben successors based on the text content of new patents. Both graphs show yearly cosine similarities between pairs of companies. Siemens is shown as third-party comparison.

G.1 IG Farben

After the breakup, IG Farben's successors continued to patent in the same broad technologies. Similarity and overlap can be defined based on technology classes to describe the broad orientation of company technology portfolios. The calculation of the comparison score starts with the set of new patents applied for in a year, grouped by their technology class. This creates a vector of 135 elements, corresponding to the number of technology classes in chemistry. Each element contains the (normalized) number of patents in the class by, for example, successor BASF. Then, the comparison score is calculated by finding the cosine similarity between the companies' vectors. Recall that the cosine similarity between two vectors is $cos(\theta)$, where θ is the angle between the two vectors. With that, the cosine similarity lies on the interval $[-1, 1]$ (on $[0, 1]$ if all vector elements are non-negative), and similarity increases with declining θ; if $\theta = 0$ and the vectors have the same orientation, the cosine similarity reaches 1. Figure G-2a plots the pairwise yearly similarity between the IG Farben successors. This descriptive plot shows that the eventual successors worked on very similar technology classes during IG Farben's existence and that the breakup did not reduce these similarities.

Although the successors continued to patent in the same technologies, their research content specialized relative to each other. I use text similarity measures based on patent full texts to look inside the technology classes (Arts, Cassiman, and Gomez, 2018). After applying the Doc2Vec algorithm (Le and Mikolov, 2014), each patent is represented as a vector v. To represent the technological orientation of a firm i, I calculate the average vector $\bar{v}_{it}$ within each year t, normalized to length one. Pairwise similarity between companies is then given by the cosine similarity between the company-year average vectors, $s_{ijt} = \bar{v}_{it} \cdot \bar{v}_{jt}$. Figure G-2b plots the pairwise yearly similarity between the IG Farben successors. In contrast to class-based similarity, text-based similarity decreases after the breakup, implying that companies, on average, specialize within technologies. As this section showed, similar results hold for the aggregate change in research trajectories within technology classes following the IG Farben breakup.

H Robustness to Historical Factors

This section discusses critical historical factors and parallel events surrounding the IG Farben breakup. As the breakup happens during one of the most turbulent episodes of German history, the core question is whether the end of the Second World War set off a complete renewal ("Hour Zero") or was rather characterized by continuity. This question was the subject of intense debate in post-war German society. Both for society and the economy historians emphasize continuity and reject notions of a radical divergence (e.g. Morsey, 2010).

When analyzing the effects of the war, the three main themes are the direct impact of the war, such as bombing, Allied occupation policies, and the separation of the Soviet occupation zone, as well as the German postwar policy and recovery. Insofar as these effects impact both IG Farben-related areas of chemistry and unrelated areas, they are a part of the parallel trends assumption justifying the difference in differences analysis. While in general untestable, in some cases, it is possible to appraise their effect by constructing appropriate control variables. Most control variables can be introduced directly in the regressions on the technology class level. Oster (2019) bounds allow an explicit assessment of biases by unobservable confounders. Robustness checks in a firm-level panel offer a different view and yield similar results. Appendix E discusses the construction of this panel and reports corresponding results.

IG Farben's involvement in the Second World War and the Nazi Regime: Nuremberg trials and managers of the successors, Auschwitz and Zyklon B, excess profits The degree of involvement of IG Farben with the Nazi regime has long been a key question of the German historical literature surrounding the company (Hayes, 1987). For the context of this study, the exact historical relationship is less important than the question whether as a result, factors emerge that could confound the estimates of the IG Farben breakup. Particularly important among them are the Nuremberg trials and their potential disruption of management, and the role of war profiteering - for example, at Auschwitz or Zyklon B, and more generally through excess profits from the war.

The loss of management personnel due to the Nuremberg trials and the subsequent reorganization could potentially have led to a initial decrease and later increase in innovation. However, although all directors of IG Farben who were alive and healthy in 1945 were indicted during a separate IG Farben trial, this did not imply much disruption in the company, and specifically not around the timing of the breakup. All indicted managers had already been arrested and replaced between 1945 and 1947, so that potential impacts would have occurred much earlier. More importantly, the managers who replaced the pre-1945 leadership brought a lot of continuity and their biographies that were very similar to those of the old guard, originating in the upper management of the plants of IG Farben itself.[45] In particular the CEOs of the IG Farben successors were all already in leadership positions in the same parts of the companies that they would subsequently take over (Heine, 1990, p. 297). For example, the post-breakup CEO of BASF, Carl Wuster (1900-1974), had been director of IG Farben and held leadership positions in the Ludwigshafen plant of IG Farben, which was later again the center of BASF. Although indicted in Nuremberg, he was acquitted and returned to the leadership of Ludwigshafen already in 1948 (Abelshauser et al., 2003, p. 367). The new CEO of Bayer, Ulrich Haberland (1900-1961), had not been indited in Nuremberg, even though he had briefly been IG Farben director. He had been in leadership positions within IG Farben since at least 1931, and since 1943 he was head of the (later) core Bayer facility Leverkusen and the surrounding plants (Heine, 1990, p. 104). At Hoechst, the new leadership formed around Karl Winnacker (1903-1989), who had long been on track to assume this position, having been promoted to director within IG Farben already in 1943 (Lindner, 2008, pp. 209–211). Nonetheless, the general impression remains that although a change in leadership occurred, it took place at an earlier time than the breakup and also not in such a way that would have disrupted the company to a great extent. Overall, it is unlikely that disruption of management personnel had a large effect on IG Farben.

Another concern is that increased innovation output could have been driven by excess profits obtained due to profiteering during the war, and - relatedly - that economic motives may no longer have played a role during the war. Corporate Germany was part of the war machinery, but companies were not nationalized – and the profit motive still applied. For example, Huber, Lindenthal, and Waldinger (2021) analyze daily stock prices as late as 1943. Generally, IG Farben's profitability was hurt by the loss of valuable export opportunities but bolstered by the general war-related demand and particular autarky projects. As a result, the stock market valuation of IG Farben itself was in line with other chemical companies and the overall market as late as 1942 (Plumpe, 1990, p. 676). Plumpe further shows that IG Farben's profitability and growth were in line or even below other large German corporations. Plumpe concludes

[45] While the biographies of the old IG Farben leadership are well-researched in the historical literature (e.g. Heine, 1990), information on the new leadership is much more fragmented.

(translated from German): "Even if the widespread belief that I.G. benefited particularly from the economic policies of the Third Reich is not compatible with the data, this does not mean that developments in the 1930s were disadvantageous for I.G. The fact that the balance sheet for the period from 1933 to 1945 was, all in all, catastrophic and ultimately ended with the dissolution of I.G. was not primarily due to economic reasons. On the contrary, the decisive factor was adherence to economic principles and acting in accordance with economic interests in an environment that was shaped by the primacy of the policies of a criminal regime." (p688).

One of IG Farben's largest and most infamous wartime investments was at Auschwitz, as briefly mentioned in Section 2.1. If completed, the facility would have contributed strongly to the production of synthetic fuels while being further outside the range of aerial attacks compared to other facilities. However, the facilities in Auschwitz were never completed and only partially entered production use. Consequently, the funds used for the investment would have presented a considerable opportunity cost but would not have been conducive to innovation per se. As for Zyklon B itself, as horrible as it is, the sales of the pesticide to concentration camps were not overly significant, amounting to a small share of domestic sales of Zyklon B during the war. The product was routinely used in civilian applications in Germany and the rest of the world; in fact, the 1952 product catalog still lists it under the brand name "Zyklon B". Further, the profits of the (partial) IG Farben subsidiary Degesch were minor relative to the profits of IG Farben itself. As a direct robustness check, it is possible to omit the field of 'Pesticides', that Zyklon B belonged to, which is part of the robustness check in Figure C-7 (Pesticides is class 16, which does not have subclasses).

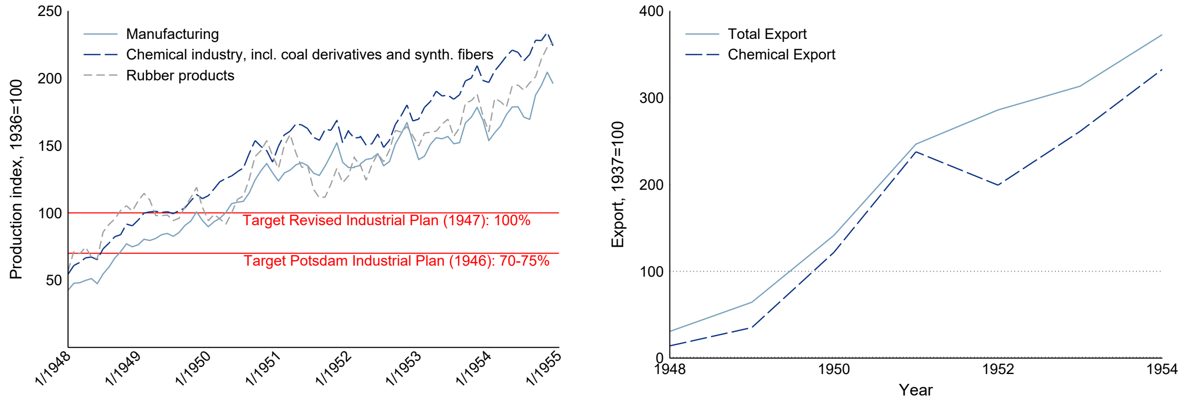
War damages The war damages to German cities were extensive, but according to the historical literature, the effect on the German industry was smaller than often thought. For example, the US Strategic Bombing Survey conducted after the war concluded that of Germany's war industry, at most 20% had been destroyed (Jeffreys, 2010, p. 295). Overall, the German economy recovered quickly and could return to pre-war export levels by 1950 (Figure H-1b). Due to their central role for war-related industries such as synthetic fuels and explosives, IG Farben facilities were likely the primary targets of Allied air campaigns. For example, the Leverkusen plant was hit by 14 aerial attacks since 1944.[46] Nevertheless, the machines were left rather intact, with only 15% of the factory beyond repair (Jeffreys, 2010, p. 295). To the extent that IG Farben facilities were specifically targeted and destroyed, the damages could result

[46]The Leverkusen example represents a middle ground for the IG story. Of the West German plants, the BASF facilities were hardest hit by the war, while the Hoechst facilities were spared. On the other hand, the Hoechst facilities suffered from underinvestment. The strongest attacks against IG plants targeted the East German synthetic fuel plants at Leuna, which were completely destroyed.

in negative effects on innovation by IG Farben successors, i.e., in smaller estimates.[47] Systematic data on the war-time destruction of companies is not available. However, the devastation of a city's housing stock is an indirect proxy. Robustness checks based on Kästner (1949) and Hohn (1991) match patents to the closest city within 10 km and assign the destruction ratio of that city. Including this proxy variable does not materially impact estimation results.[48]

Figure H-1: Germany's economic recovery

(a) Production recovery (b) Trade recovery



Notes: H-1a: Monthly German production index with reference level 1936. H-1b: Yearly German chemical and total exports with reference level 1937. Source: Statistical yearbooks for West Germany.

Besides damage to the physical infrastructure, the war may have led to the loss of life through battles and aerial attacks. In the wake of a re-appraisal of its history, the German Chemical Society studied public death announcements as well as internal information about the fate of its members (Maier, 2015). They found the death rate of chemists to be vastly below the general male population (2.7% vs. 16.8%), for example, because many Society members of military age were exempt from service. Although deaths were concentrated among junior members, the Society concluded in 1947 that even losses among the younger generation had not been 'overly large' (Maier, 2015, p. 570).

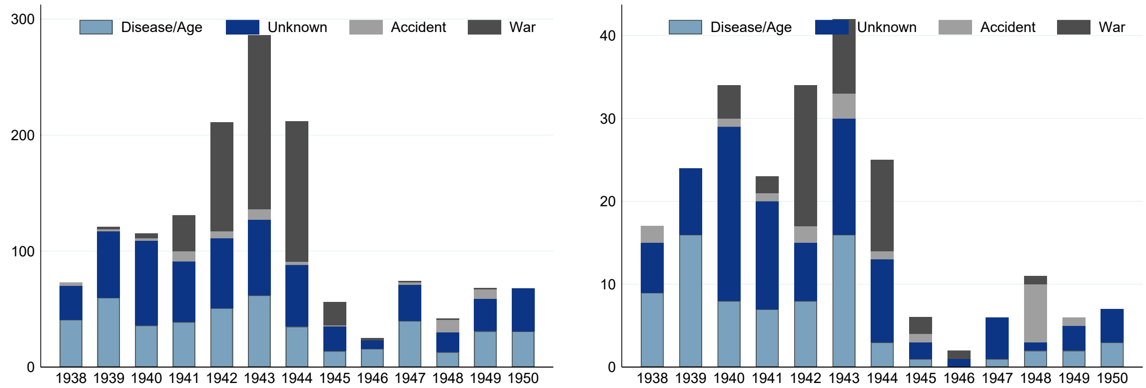
Figure H-2 reports descriptive statistics derived from death notices in journals of the German Chemical Society. Deaths are underreported for 1945 and 1946, as the publication of the journals first ceased and then resumed in 1947. Even so, the data suggest that most deaths were concentrated among (doctoral) student members of the Society. The median age of the war-related deceased was 27, and only 25% were older than 34. Even within IG Farben, the

[47] Yet, Waldinger (2016) exploits bombing damage to universities and does not find long-run effects on research output. Likewise, Baruffaldi and Gaessler (2021) find that the loss of research infrastructure has little effect on research output over ten years. Renewal of obsolete infrastructure might even have a positive effect.

[48] Table 5 shows that the destruction ratio does not vary between technology classes differentially exposed to the IG Farben shock. In technology-level (Tables C-2), firm-level (Table E-2), the inclusion of war destruction as a control variable does not alter results.

Figure H-2: Deaths of German Chemical Society members

(a) All reported deaths | (b) Reported IG Farben deaths



Notes: Shows the number of death notices in journals of the German Chemical Society (Angewandte Chemie, Chemische Fabrik, Chemie-Ingenieur-Technik) by reported cause and year of death. The left panel shows all listed deaths, the right panel only IG Farben chemists. War-related deaths after 1945 are prisoners of war.

median age for war-related death is 35. Between 1939 and 1945, 25% of reported deaths were war-related. The decrease in deaths after 1945 is likely due to a decrease in the overall workforce, possibly selected by age.

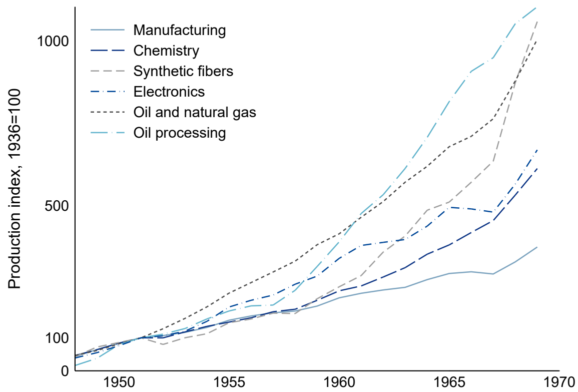
Allied economic policies, German recovery and technological opportunity In the initial period after the war, with the economy in disarray and the population's basic needs unmet, the Allies assumed direct control over the economy. With this initially came a set of production restrictions. These were primarily targeted toward dismantling all war-related capacity, discussed in detail below, and the restriction of strategic goods production. Table H-1 in the appendix gives a detailed account of the relevant products and industries and the development of the regulations over time. According to the 1946 Potsdam Industrial Plan, the German economy was to be limited to 70-75% of the pre-war 1936 level. The ceilings were never reached before the 1947 Revised Industrial Plan increased figures to 100% of the 1936 level. By mid-1950, also this restriction was lifted. After the middle of 1950, restrictions were still placed on war-related chemicals and some parts of the plastics value chain. These were only relaxed in 1951.

For the empirical strategy, relaxations in the 1950s are of the largest concern. If these relaxations would differentially affect production areas with IG Farben activity, they would constitute a parallel event of concern. In particular of concern is the plastics industry, where relaxation only occurred by 1951. Robustness checks thus repeat the analysis while disregarding technology classes relevant for the plastics industry (Table C-2). The consistency of results is also reassuring, given the dominance of IG Farben in these fields. The removal of restrictions on the civilian industry by the Petersberg Industrial Plan, effective in late 1950, is unlikely to have significant confounding effects. First, the restrictions did not regulate individual products within a broad class of chemicals. Fixed effect controls for the broad chemical class are available. Second, removing restrictions did not lead to an immediate, marked increase in production. Figure H-1a shows the output of the German manufacturing and chemical industry relative to the pre-war level. The chemical industry did not show a substantial output increase in mid-1950, indicating that the policy was either not binding or that not much additional capacity was available. This is consistent with the historical literature (Morsey, 2010, p. 5).

The swift German economic recovery and the economic boom starting in the early 1950s could confound the IG Farben shock. However, the number of granted patents in technology classes not exposed to the breakup does stay constant, both within and outside of chemistry, see Figure 5b. It is hard to think of a technology-level comparison that alleviates these concerns. If the economic shocks driving the recovery were global (e.g., the Korean war), they would similarly affect counts of, e.g., US patents. Even if they were specific to technologies in Germany, affected German companies' patenting activities would likely spill over to other patent systems. A better argument is that in product-level price regressions (see Table 3) - effects can be traced to such products where multiple IG Farben successors were active. It is unlikely that macroeconomic shocks driving recovery and boom exactly correlate with the microstructure of the IG Farben successors' product portfolios.

More broadly, the historical narrative has it that IG Farben specifically invested in technologies at the technological frontier. In particular, the transition to oil-based chemistry and the development of modern plastics throughout the 1950s come to mind. If IG Farben had picked future winners and past investments started to pay off after the Second World War, the analysis could be picking up the omitted variable of technological opportunity. This alternative hypothesis is inherently difficult to assess as technological opportunity is difficult to measure independently from technological success. However, the argument contrasts with other historical narratives and empirical results. For one, much of the technology developed for the target of German autarky was not immediately applicable in the post-war world. Specifically, oil-based chemistry was a distinctly post-war development for the German chemical industry (Stokes, 1994). Further, the increase in patenting in technology classes affected by the breakup is not driven by any particular technology area. Results remain consistent even after, in turn, omitting every group of technology classes, see Figure C-7. The aggregate output growth of chemistry is on par with the overall economy and accelerated only in the 1960s. The same is true for synthetic fibers (see Figure H-3). Output in chemistry even stays below other sectors such as electronics, and the category of oil and oil processing dwarfs both.

Figure H-3: Industrial production (long-run)



Notes: Index of net industrial production. Synthetic fibers is a subset of chemistry. Time series reported in 1956, 1965 and 1971 are reset to base year 1951 and chained to create the long-run index. Source: Statistical Yearbooks for West Germany.

Dismantlement of factories After the war, the Allies sought to limit Germany's war potential and recuperate some of their own economic losses. The extent and impact of these policies can be captured using data given by Harmssen (1951, pp. 98–126). Harmssen prints the official dismantlement targets for the Western Zones as of 1947 and reported dismantlements for the Soviet zone. There are almost 2000 factory entries pertaining to some 1700 firms. However, only 100 firms in the chemical industry occur in the dismantlement lists, consistent with the over 80% of entries classified as aerospace, defense, machinery, or mining. The list of actually dismantled plants is much smaller as the Western allies adjusted the lists. The list of dismantlement targets for the Western zones starts with 1500 entries and is halved by 1949 (Wallich, 1955, p. 369). For a technology class analysis, the share of patents by firms slated for dismantlement can be calculated. Among non-IG Farben firms, around 8% of pre-war patents were applied by targeted firms, balanced between classes by IG shock exposure. Controlling for this variable leaves results unchanged.[49]

Next to the effect of dismantlements in the broader chemical industry, the effect on IG Farben is important. IG Farben was a primary target, and all factories were contained in the lists. This mechanically leads to a strong correlation between breakup exposure and dismantlement share on a technology class level. Studying the issue in more detail, it is unlikely that damages to the IG Farben successors through dismantlement drive the effect. Some plants on the dismantlement lists were to be fully disassembled or destroyed. However, most of the time, only parts of listed plants were intended for dismantling. For example, IG Farben in Leverkusen was set to lose

[49]See Table 5 and Table C-2, respectively. The firm-level regressions in Table E-2 show that the patent output of firms exposed to dismantlement permanently suffers, but the estimates for IG Farben exposure remain unchanged.

production facilities for seven types of chemicals, a small subset of its portfolio.[50] In West Germany, whole plants were slated for dismantlement only in the French zone. Abelshauser (2003, pp. 349–350) discusses their history. After much controversy, dismantlements only affected synthetic fuels and plastics. Crucial other plants were saved. If dismantlements had been realized as originally intended, they would have implied considerable damages for the recovery of BASF. Ultimately, they never affected the supply of in-house production or other industries. While lacking counterfactuals, it is notable that the IG Farben successors could recover quickly to pre-war levels of economic activity, as discussed in Section 7.

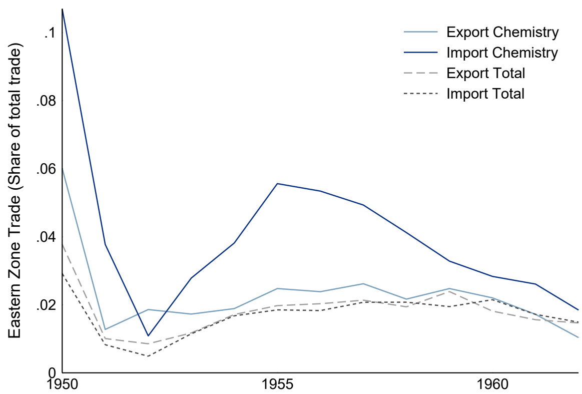
The Soviet sector and German separation Quickly after Germany's liberation and the division into occupation zones, the Soviet sector started to develop on a diverging path. Here, the authorities introduced the harshest reparation policies. Large parts of the surviving industry were dismantled and brought to the Soviet Union. As in the Western zones, the Soviets took direct control of the IG Farben plants even before nationalization efforts were begun in earnest. Stokes (1995) discusses the history of IG Farben in East Germany after 1945. Latest with the currency reforms in East and West, West and East German industry began to disintegrate. The supplier lists of 1952 list no East German chemical firms. Figure H-4 shows the importance of interzonal (East-West) trade by comparing it with overall trade. Visibly, interzonal trade was initially important, but the amount declined in the 1950s and never recovered. Before the Second World War, a sizable share of chemical companies was located in East Germany or Berlin. Of those, some were able to relocate their operations and are still active in West Germany in 1952. For inventive activity, it is possible to control for the pre-war share of inventive activity taking place in the Soviet sector. Dismantlement targets for the Soviet sector are available from Harmssen (1951).

Robustness checks can account for differential exposure to the Soviet sector. For innovation, analysis on the technology class and firm levels is feasible. Table 5 shows that patents in technologies with and without exposure to the IG were located in East Germany with the same rate. However, the share of patents located in Berlin is higher for IG-exposed technologies, consistent with some IG plants located there. Explicitly controlling for the share, Table C-2 finds estimates unchanged. Firm-level regressions in Appendix E explicitly introduce control variables and show the robustness of the innovation analysis.

Allied competition policy and the dissolution of cartels Before the war, the German laws regulating cartels were anti-competitive, as considered from today's perspective. Maintaining

[50]Listed were, for example, a drug against Malaria, some plastics, and substances relevant as rocket fuel. Bayer still offered all substances listed in the 1952 product listing. See Table H-3 for the 1947 dismantlement entries related to IG Farben.

Figure H-4: East-West trade flows



Notes: Interzonal trade as a share of total trade, in the chemical industry and total. Earlier numbers are not available from statistical yearbooks. Source: Statistical Yearbooks for West Germany.

high prices to strengthen the industry was a policy objective. Cartels were allowed, and their general form was regulated by law, to the extent that Germany's cartel court was largely arbitrating grievances between cartel members. Early during the Allied occupation, in 1947, such cartels were dissolved. However, Germany itself did not introduce competition regulation until 1958 (Murach-Brand, 2004). Whether the 1947 dissolution of cartels affected the innovation activities of chemical companies is unclear, but for example Kang (2020) suggests a negative effect. In principle, areas with IG Farben activity (see for example Stokes, 2016, p. 174) and such without were affected, and cartels were frequent throughout the economy. Nevertheless, since IG Farben was the dominant force in its areas of activity, the effect in non-IG areas would likely be stronger. Therefore, if patenting activity in non-IG areas drops more strongly immediately following the war, this could be a reason. In product catalogs,

As cartels were publicly supported institutions, cartel membership was often public information and can be controlled for statistically. The 1939 product catalog details which products are to be procured from cartel organizations directly. Similarly, for listed companies, firm directories also include information about cartel memberships. Combining this information, the effect of the dissolution of cartels can be directly accounted for. In the data, there are 42 cartels supplying 122 products, among which 48 have price information available. Of those, 21 are offered by cartels with IG Farben association. Cartels with IG Farben membership have a particular role. The 1939 data contains 8 such cartels, most prominently the "Stickstoff-Syndikat" (Nitrogen syndicate), which was dominated by the IG Farben group. I consider products supplied by these cartels as supplied by IG Farben. Price results reported in Section 4.1 (Table 3) are robust to including a control for the presence of cartels.

Tariff Changes from Germany's GATT Accession Effective October 1951, Germany entered the General Agreement on Tariffs and Trade (GATT), the precursor of today's World Trade Organization. Germany's tariff system was thoroughly reformed, and many tariffs changed. To capture the effect, tariff levels based on the pre- and post-reform schedules (Lang, 1939; Bundesministerium der Finanzen, 1951) are matched to individual products. The previous schedule had not undergone major reforms since 1902 and was, with only short interruptions and exceptions, still in effect in 1951 (Jerchow, 1979). The 1902 system imposed a specific tariff that leveraged fixed amounts per unit of imported goods. In 1951, structure, level and type of tariff were changed. Afterwards, a largely ad valorem tariff, leveraging fixed percentages of imported goods' values, was introduced. Knowing the prices per volume, the two systems can be compared. The change increased tariffs, reportedly to - unsuccessfully - gain leeway for GATT negotiations, and put Germany in an intermediate position compared to other European countries (Wallich, 1955, pp. 257–258). In the covered chemical products, tariffs changed from an average of 9.1% to 14.9%. In price regressions, controls for dynamic effects of the tariff changes do not strongly influence the estimates for the IG Farben shock, see Section 4.1 (Table 3).

The German Patent Office West Germany's legal environment for intellectual property itself, however, was not significantly altered from its 1936 version, in stark contrast to East Germany and the newly formed German Democratic Republic. Patents from this new system do not play a role in this paper. Nonetheless, the (West) German Patent Office needed some time to reactivate after the war. From 1948 onward, patent applications could be filed but were not immediately processed. In a transition period, patent examination was conducted only to a limited extent, but the situation had normalized by 1951. The difference-in-differences approach will capture many time-variant aspects relevant in the first post-war years. For example, the comparatively high number of patents filed in 1949 and 1950 is visible in descriptive statistics but occurs in both highly affected and less affected technologies (Figure 5b). Nonetheless, some factors related to the patent system may have been time-varying and differential across technologies. To address this concern, I empirically test whether the speed of patent prosecution (and examination as part of that), measured as the lag between application and publication year, significantly changed for technology classes exposed to the breakup. This is, in fact, the case, and after 1951, exposed technologies appear to see reduced publication lags (Figure C-6a). The effect, however, has different temporal patterns compared to the effect of the breakup, and, reassuringly, including the publication lag as a control variable in the baseline regression does not affect the estimates (Figure C-6b). This is in line with the discussion on the propensity to patent in Section 6.4, the increased value of IP may have induced applications to seek faster procedures or speed up their own communication with the patent office. Yet, the faster patent prosecution appears as a side-effect rather than a central mechanism. See Section A.1 and Figure A-2 in the appendix for more information and descriptive statistics on publication lags.

Other factors Next to the previously discussed factors, others elude measurement attempts. Direct expropriation and exploitation of German intellectual property and tacit knowledge occurred during and after the war. German IP in foreign countries was confiscated, and the Allied survey groups took stock of German firms' technology level. Scientists - especially in war-related fields such as rocketry and chemical weapons - were recruited (Jacobsen, 2014). The effect of these policies is not easily quantifiable. Historians who tried to judge their economic impact determined it to be large and significant (Gimbel, 1990). On the other hand, confiscated technical specifications often required additional tacit knowledge (Stokes, 1991, p. 15) or were about to be obsolete due to new technological developments (Murmann and Landau, 2000, p. 61). To the extent that civilian research was concerned, contact between US and German scientists might have helped to facilitate post-war collaboration. The results of Baten, Bianchi, and Moser (2017) suggest that such policies positively affect subsequent innovation, resulting in a possible upwards bias. Whether such a bias materializes depends on whether the policies more strongly targeted fields with IG Farben activity. However, Allied technical survey efforts covered a broad set of targets.[51] In a rough approach, including a proxy for the exposure to the confiscation of foreign IP does not change the conclusions about the IG Farben breakup.[52] Labor-related channels are beyond the scope of this paper. These include the loss of life during the war (but see the discussion under 'war destruction' above), the relocation of East-German inventors, and the change in monopsony power in the labor market (but see Section 6.8 for a discussion of IG Farben inventors). Oster (2019) bounds allow an explicit assessment of biases by unobservable confounders. Table C-7 shows corresponding results.

[51]Gimbel (1990, pp. 64–67) details the cases of chemical companies Merck, Degussa, and Linde next to IG Farben and its subsidiary Wacker. The survey teams worked on 20,000 targets, later narrowed to 400.

[52]Table E-2 includes the ratio of pre-war US patents by pre-war German patents of individual firms. Firms with larger exposure increase their post-war patenting, but the coefficients of breakup exposure do not change much. While this result is compatible with Baten, Bianchi, and Moser (2017), a full analysis would require more nuance.

Table H-1: Post-war production and capacity restrictions until 1951

Materials	Potsdam Industrial Plan	Revised Industrial Plan	Washington/Petersberg Industrial Plan	Agreement on Industrial Monitoring
Announcement	Mar 46	Aug 47	Apr 49 / Nov 49	Apr 51
Effect	N/A		Sept 50	Apr 51
Target level	70-75% of 1936 Dismantle 1500 plants	100% of 1936 859 plants, later 700	Unrestricted Dismantlement stop	Unrestricted
Chemical industry				
Basic chemicals Others chemicals Pharmaceuticals Colors	40% of 1936 70% of 1936 80% of 1936 36k t Export restricted	98% of 1936 97% of 1936 84% of 1936 96% of 1936 Export allowed	Unrestricted	
Synthetic ammonia	Prohibition of production		Post-dismantlement capacity	None
Chlorine	Basic chemicals / Only upon approval		Post-dismantlement capacity	None
Synthetic fuels	Prohibition of production			Monitoring
Plastics value chain				
Styrene	70% of 1936	100% of 1936	20k t	None
Butadiene	Not mentioned		Prohibition of production	
Synthetic rubber, gum	Prohibition of production (ex. small Q)			Monitoring
Synthetic fibers	185k t	Not mentioned	None	
Consumer products	Q Restrictions	Unrestricted	None	
Metals				

Table H-1: Post-war production and capacity restrictions until 1951

Materials	Potsdam Industrial Plan	Revised Industrial Plan	Washington/Petersberg Industrial Plan	Agreement on Industrial Monitoring
Copper, zinc, lead, tin, nickel	ca. 50% of 1936	up to 100% of 1936	None	
Aluminium	Prohibition of production		Capacity restriction	None
Magnesium	Prohibition of production			
Beryllium	Prohibition of production			None
Vanadium	Prohibition of production		None	
War-related products	Prohibition of production			
War material, including explosives, warfare gases, biological weapons				
Firearm propellants, e.g. Nitroguanidine, Nitroglycerin, Diethylene glycol, Nitrocellulose				
Rocket fuels: Hydrogen peroxide (>37%), Hydrazine hydrate, Methyl nitrate				
White phosphorus and other burn agents				

Notes: Summarizes post-war production restrictions until 1951. Not all restrictions laid out came into effect. For example, the Potsdam Industrial Plan had little practical consequence. This was due to a breakdown of coordination among the Allies and changed priorities in the wake of the coming Cold War. Also, the German industry did not reach ceilings before they were adjusted (Morsey (2010, p. 5) and Wallich (1955, p. 369)). Exemplary, with respect to plastics and synthetic ammonia, the Potsdam plan outlawed production, but halted this restriction until sufficient imports were viable. After this, all capital equipment should be removed. Specialized metals are listed as IG Farben subsidiaries were involved in their production. Aluminium, Magnesium, Beryllium and Vanadium are either light metals or ingredients for specialty steel.Butadiene and Styrene - in 3:1 ratio - are ingredients for the synthetic rubber "Buna", among other chemical substances. Styrene was only explicitly regulated in the Washington Industrial Plan, before it was regulated as 'generic chemicals'. With the Washington Agreement, capacity restrictions on civilian production such as cement, paper, textiles and shoes, cars, trains etc. were lifted. Other goods more tightly restricted were steel, heavy machine tools, aircraft, ships and electronic and optical components. Under the agreement on industrial monitoring (1951), industries such as synthetic rubber and synthetic fuels required approval for capacity expansion, but were otherwise free to operate. Source: Harmssen (1951). Factory numbers from Wallich (1955, p. 369).

Table H-2: Plants within IG Farben

Plant	Work group	Successor	R&D	Patent	Description
British zone					
Dormagen	Lower rh.	Bayer	Y	N	
Elberfeld	Lower rh.	Bayer	Y	N	
Leverkusen	Lower rh.	Bayer	Y	Y	Core of successor Bayer
		Agfa			Photo materials
Uerdingen	Lower rh.	Bayer	Y	Y	
Zweckel	Upper rh.	Bayer	N	N	
Hüls	Upper rh.	Hüls	N	N	Plastics. From 1938, joint venture with Hibernia AG (under IG leadership)
US zone					
Höchst	Middle rh.	Hoechst	Y	Y	Core of successor Hoechst
Griesheim	Middle rh.	Hoechst	Y	N	
G.-Autogen	Middle rh.	Hoechst	Y	Y	Industrial gases, located at Griesheim
Bobingen	Berlin	Hoechst	Y	N	Artificial Silk
Offenbach	Middle rh.	Hoechst	Y	Y	
Mainkur	Middle rh.	Cassella	Y	Y	As subsidiary
Wiesbaden	Middle rh.	Kalle	Y	Y	As subsidiary
Munich	Berlin	Agfa	Y	Y	Camera manufacturing
Gendorf		Hoechst			Chemical warfare gases, subsidiary, independent 1952-1955, then Hoechst
French zone					
Ludwigshafen	Upper rh.	BASF	Y	Y	Core of successor BASF
Oppau	Upper rh.	BASF	Y	Y	
Rheinfelden	Middle Ger.	Dynamit	N	N	Artificial silk
Rottweil	Berlin	Rottweil	N	N	Explosives and artificial silk, later as Rottweiler Kunstseidefabrik AG
Soviet zone					
Aken	Middle Ger.	IG East	N	N	Light metals (from 1934)
Wolfen-Film	Berlin	IG East	Y	Y	Photo materials and artificial silk
Wolfen-Farben	Middle Ger.	IG East	Y	Y	Colors
Schkopau	Upper rh.	IG East	N	N	From 1937, before Leuna
Leuna	Upper rh.	IG East			Ammoniakwerk Merseburg
Premnitz	Berlin	IG East	Y	N	Artificial silk. Very small patent-related expenditure
Bitterfeld	Middle Ger.	IG East	Y	Y	
Döberitz	Middle Ger.	IG East	N	N	Artificial silk. Near Premnitz

Notes: IG Farben plants and their organization according to works groups (Betriebsgemeinschaften - among them Lower, Middle and Upper rhine, Middle Germany and Berlin) and according to successor companies. Further lists the existence of R&D and patent offices as given by internal IG Farben accounting documents from 1935-1939. These are unavailable for some subsidiaries, e.g. Leuna or Anorgana. See also Plumpe (1990, p. 142). Smaller plants at Bochum, Karlsruhe, Gapel, Teutschenthal, Staßfurt, ... omitted. Foreign plants omitted. Subsidiaries - except selected - omitted. Groups as after 1926. Autogen and IG subsidiaries involved primarily in the production of industrial gases became part of Knapsack-Griesheim AG under the leadership of Hoechst.

Table H-3: Dismantling of IG Farben

Successor	Plant	Type	Products / Description
British-American zone			
Bayer	Dormagen	Part	Perlon (en: Nylon)
Bayer	Elberfeld	Part	Cellulose derivatives, artifical resins
Bayer	Holten	Part	1,2-Dichloroethane
Bayer	Leverkusen	Part	Sodium sulfide, "Atebrin" (Mepacrine), polyamides, artificial resins, hydrazine hydrate (Propellant), activated carbon, toluene nitrate (Explosives)
Bayer	Uerdingen	Part	Chloride, causic soda, alkydal artifical resins
Bayer	Zweckel	Part	Diethyl ether, 1,2-Dichloroethane, polyethylene, bleaching powder
Other	Duisburg	N/A	Liquid oxygen
Anorgana	Gendorf	Part	Bleach und sodium hydroxide, acetaldehyde, glycol
Wacker	Burghausen	Part	No details
Kalle	Wiesbaden	Part	Methyl, ethyl, Cellulose derivatives
Hoechst	Frankfurt/M	Part	"Uresin" (Pastics), acetate, carboresin, black sulfur, solvents, chloride solutions, dinitrobenzene
Hoechst	Griesheim	N/A	Industrial gases
Other	Kassel	N/A	Industrial gases
Dynamit	Fürde/Grevenbrück	Part	Explosives, fuses
Dynamit	Schlebusch	Part	Glycerine, toluene nitrate
Dynamit	Troisdorf	Part	Nitrogen, vulcanized fiber, phenol formaldehyde resin, celluloid
Dynamit	Claustal-Zellerfeld	Part	High explosives, grenades
Dynamit	Empelde-Hannover	Full	Ammunition
Dynamit	Near Hamburg	Full	(At Düneburg/Krümel) Explosives
Dynamit	Nürnberg	Full	Bullet casings
Dynamit	Kauferin/Landsberg	Full	Ammunition
Dynamit	Stadeln	Full	Bullet casings
Dynamit	Hamm	Full	Gunpowder
French zone			
Other	Rottweil	Part	Hunting ammunition
BASF	Ludwigshafen	Full	38 plants (unspecified)
BASF	Oppau	Full	11 plants (unspecified)
Other	Rheinfelden	Full	Unspecified
Soviet zone			
IG East	Aken	Full	
IG East	Wolfen	Full	Agfa plants
IG East	Schkopau	Full	Buna plant
IG East	Leuna	Full	Leuna plant

Table H-3: Dismantling of IG Farben

Successor	Plant	Type	Products / Description
IG East	Piesteritz	Full	Nitrogen plant
IG East	Bitterfeld	Full	
IG East	Coswig	Full	(Former WASAG)

qualifications contained in the lists of the dismantlement targets, if available. Soviet zone lists actual dismantlements. In the Western zones, actual dismantlement rarely reached the originally intended level, see discussion in Section H.

Notes: Dismantlement targets as reported in Harmssen (1951), lists as of 1947. Type of dismantlement and product/description lists

I Technology classes

Table I-1: Technology classes in chemistry

Class	Description
1:	Processing of ores, fuels and other minerals, including waste and combustion residues
1A	Treatment other than magnetic, electrical and floating treatment
1B	Magnetic and electrical processing
1C	Floatation treatment, also differential sedimentation
2:	Bakery
2C	Chemical and biological processes for flour treatment and dough preparation, as well as production of baked goods, baking products and baking aids
3:	Clothing
4:	Lighting from fuels and heating burners in general
4C	Gas containers, pressure regulators in the pipe network and consumption regulators for lighting and cooking purposes, circulation regulators for compressed gas systems, line and distribution of gaseous fuels, mixing devices for gas and air, etc. The like for gas works, systems for compressed gas production
4D	Ignition and extinguishing devices, including electrical ones, unless they are a switch construction
4E	Catalytic gas self-ignition
5:	Mining
6:	Fermentation industry: alcohol, brandy, beer, wine, vinegar, yeast and other fermentation agents and products, enzymes
7:	Sheet metal, metal tubes, wire production and processing, as well as metal rolling
8:	Bleaching, laundry, dyeing, fabric and wallpaper printing and finishing
8A	Bleaching, dyeing, mercerizing, impregnating, washing of spun fibers, yarns, fabrics, knitted fabrics, etc., fulling of fabrics and the like. Mechanical part
8H	Covering materials: Linoleum, Linkrusta, oilcloth, wallpaper and other covered fabrics, mechanical part
8I	Bleaching and washing, chemical part
8K	Textile treatment, chemical part, in particular textile finishing using material means and through chemical action, with the exception of the treatment of staple fibers - 29b -
8L	Covering materials: linoleum, oilcloth, roofing felt, etc. coated fabrics, chemical part
8M	Dyeing and mordanting, chemical part, development of colors on the fiber, preparation of dyes
8N	Fabric printing and other surface decorations on textile materials, chemical part fabric printing
8O	Fiber protection agents, wetting agents and foaming agents in general
9:	Bristle goods
10:	Fuels
10A	Coking, smoldering, charring
10B	Manufacture of fuel briquettes, firelighters and the like, mooring of liquid fuels, refining of fuels
10C	Peat extraction, processing of peat into fuel
11:	Bookbinding, albums, letter folders and folders
12:	Chemical processes and apparatus, unless they are listed in special classes
12A	Cooking processes and vessels for chemical purposes, evaporation, concentration, distillation for the chemical industry, condensation
12B	Calcination, melting
12C	Extinguishing, leaching, crystallizing, condensing liquid substances
12D	Clarifying, cutting and filtering liquids and liquid masses
12E	Absorbing, cleaning and separating gases and vapors, mixing solid and liquid bodies as well as gases and vapors with each other and with liquids
12F	Lifters, vessels and closures for acids and charging devices, inflow and outflow regulators
12G	General purely chemical processes in the chemical industry and associated apparatus
12H	General electrochemical processes and apparatus
12I	Metalloids and their compounds other than those mentioned under 12k
12K	Ammonia, cyanide and their compounds
12L	Compounds of alkali metals
12M	Compounds of alkaline earth and earth metals
12N	Compounds of heavy metals
12O	Hydrocarbons, alcohols, aldehydes, ketones, organic sulfur compounds, hydrogenated compounds, carboxylic acids, carboxamides, ureas and compounds not otherwise mentioned
12P	Nitrogen rings, nitrogen-containing compounds of unknown constitution
12Q	Amines, phenols, naphthols, aminophenols, aminonaphthols, aminoanthracene compounds, oxygen, sulfur and selenium rings
12R	Processing of tars and tar fractions from solid fuels, e.g. raw benzene and pitch; Wood vinegar extraction, extraction of coal, peat and the like, extraction and refining of montan wax
12S	Production of dispersions, emulsions and suspensions, i.e. the distribution of any chemical substances in any medium, or use of chemical substances or mixtures of substances as dispersants or stabilizers in general - chemical part. -
13:	Steam boiler for power operation along with equipment and steam pipe
14:	Steam engines, steam power plants and storage systems for fresh and exhaust steam that are independent of the steam boiler
15:	Printing shop, liners, typewriters, stamps
15K	Printing and reproduction processes including color embossing, special printed products, preparation
15L	Materials for graphic printing, e.g. plates, materials, printing inks, dampening and washing solutions, cardboard
16:	Fertilizer preparation and animal corpse processing, chemical soil culture and fertilization processes
16	Fertilizer preparation and animal corpse processing, chemical soil culture and fertilization processes
17:	Ice and cold production, ice storage, heat exchange, liquefaction of gases and gas mixtures that are difficult to condense, such as air, by mechanical means.
17A	Refrigeration machines
17B	Ice production and extraction
17C	Ice cellars, refrigerators, freezers, refrigerated trucks
17D	Steam condensers
17E	Open heat exchange devices in which the heat exchange means come into direct contact
17F	Closed heat exchange facilities in which the heat exchange means are separated by a solid wall
17G	Liquefaction and separation of gases and gas mixtures that are difficult to condense using mech. ways and decanting and evaporation of liquefied gases; Pressure vessels and insulated vessels for compressed and liquefied gases
18:	Ironworks
19:	Railway, road and bridge construction
20:	Railway operations
21:	Electrical engineering
21B	Galvanic elements, collectors and thermocouples
21C	Electrical wiring and installation: cables and overhead lines, insulators, switches, regulators, switching methods, line protection, fuses and lightning protection devices
21G	General electrical auxiliary equipment and processes other than electrochemical: magnets, self-interrupters, capacitors, valves, discharge tubes, X-ray apparatus, electrotherapy and radiotherapy equipment, photocells
22:	Paints, varnishes, varnishes, paints, adhesives
22A	Azo, azoxide and hydrazone dyes in substance and on the fiber
22B	Acridines, anthracene dyes, di- and triarylmethane dyes, phthaleins, pyronines, oxyketone dyes
22C	Azines, Oxazines, Thiazines, Indulines, Safranines, Eurhodines, Indophenols
22D	Sulfur-containing dyes
22E	Indigo, thioindigo and other dyes not mentioned under 22a-d
22F	Pigment colors: mineral and bronze colors, colored varnishes
22G	Inks, marking colors, art paints, pearl essence, paint binders, shoe polishes, floor polishes, paints, embossing foils, paint strippers, cleaning, polishing and cleaning products
22H	Resins, varnishes, lacquers, drying agents, polishes, mixtures containing tar and pitch, synthetic asphalts
22I	Smocks, glue and other adhesives, sealants
23:	Fat and oil industry
23A	Extraction and purification of fats, fatty oils, waxes and essential oils, compilation of fragrances
23B	Extraction of mineral oils by chemical processes, distillation, refining and splitting of mineral oils, extraction and refining of paraffin and earth wax, lighting and heating oils
23C	Lubricants and dispersions
23D	Fatty acids, candles, chemical part, also stills
23E	Soaps, soap preparations, glycerin, chemical part, also saponification and distillation apparatus
24:	Firing systems
24B	Firing systems with liquid fuels
24C	Gas firing systems, including regenerative firing systems, with accessories, retort and muffle furnaces, refractory furnaces
24E	Gas generators or generators, gasification of solid fuels using a gasification agent, e.g. air, water vapor
24G	Chimney equipment, cleaning closures for chimneys, chimney sweeping devices, cleaning of boiler pipes and flue gas preheaters, combustion and heating ducts from combustion residues, collecting, extinguishing, crushing and removing combustion residues, separating solid, liquid and gaseous products from flue gases
25:	Braiding, lace making, knitting, trimmings, tapestry and net making
26:	Gas production by degassing fuels, e.g. luminous gas and oil gas; Wet fuel gas production; Fuel gas production by carburizing; Distillation gas and acetylene purification
26A	Gas production through dry distillation, including subsequent gasification of the fuels and post-treatment of the gases
26B	Wet fuel gas production, especially acetylene production
26C	Fuel gas production by carburizing, especially air
26D	Purification of distillation gases from fuels and acetylene purification
26E	Loading and unloading devices for gas retorts
27:	Blowers, air pumps or compressors
28:	Tannery, treatment of hides, leather processing and leather processing
28A	Chemical treatment and processing of furs, hides and leather, including natural tanning agents and artificial tanning agent mixtures, soaking and preserving leather
29:	Web fibers
29A	Mechanical extraction of spun fibers
29B	Chemical extraction or production of spinning fibers and threads as well as their preparation for further textile processing
30:	Healing treatment
30A	Instruments and devices for diagnostic and surgical purposes including obstetrics, including devices for testing professional suitability, corn knives, vaccination devices and auxiliary devices for surgical purposes

30B Dental surgery, dentures, tooth cleaning, toothpicks, mouth rinsing devices, dental and oral care devices
30C Veterinary instruments and equipment
30D Artificial limbs, splints, bandages, bandages, bandages and wraps, eye and ear treatment, eye and ear protection
30E Patient transport and storage, special health-promoting storage, beds, operating tables and chairs, including dental and funeral equipment
30F Remedial gymnastics, massage, bathing and washing facilities for special healing purposes and individual body parts
30G Pharmaceutical containers, equipment and machines, feeding bottles and lollipops
30H Drug production - as long as it does not involve the synthesis of chemically uniform compounds - dental treatment and tooth-preserving products chem. part, X-ray contrast media, cosmetic products, bacteriology, biology
30I Disinfection and sterilization, procedures and apparatus, dressing materials, surgical sutures and means for tying off blood veins, corpse preservation
30K Suction, pumping, rinsing, spraying and atomizing devices for medicinal, disinfectant and hygienic purposes; inhalation, breathing, anesthesia and euthanasia devices; Probes, catheters, dilators, devices for introducing medicinal products into body cavities
31: Foundry of all kinds of metals, including the associated molding shop
32: Glass
32A Manufacture, shaping, reshaping, as well as treatment of glass, quartz glass and the like after shaping
32B Chemical composition of glass: glass sets, fluxes, coloring and discoloring, changing the surface quality of the glass: cathedral glass, etching, sandblasting processing, stained glass, coating glass with glass or metal, artificial glazing
33: Handheld and travel devices
34: Household machines, devices and objects of all kinds, as well as furniture
35: Hoists
36: Heating, ventilation, hot water supply in buildings
37: Structural engineering
38: Woodworking, mechanical and chemical
38H Means, processes and devices for drying and impregnating, e.g. leaching, preserving, making fireproof, coloring and staining wood, pipe, cork and similar materials
39: Horn, ivory and other carving materials, rubber, gutta-percha and other plastic materials, shatterproof glass with plastic materials, and production of synthetic resins, especially resinous condensation and polymerization products
39A Mechanical part
39B Chemical production of plastic compounds, including braking and grinding compounds, as well as thermal and acoustic insulating compounds
39C Production of synthetic resins, in particular resinous condensation and polymerization products
40: Metal metallurgy, metal alloys, electrometallurgy and refining of metals and metal alloys
40A Metal metallurgy
40B Metal alloys
40C Electrometallurgical metal extraction using electrolytic or electrothermal methods, also in powder form
40D Refining of non-ferrous metals and alloys
41: Hat making and felting
42: Instruments
42K Force gauges, pressure gauges, indicators, test channels, test stands for buildings, construction and machine parts, for internal combustion engines, hollow bodies and vehicles, testing devices for springs, tools, for measuring deflections and for determining the load-bearing capacity of the subsoil, road testing machines, leak testers, Balancing machines, material testing of metallic materials and non-metallic solid materials, testing of textiles, rubber, leather, paper, paints and glues
42L Chemical and physical processes and apparatus for examining substances
43: Checkpoints and self-cashiers
44: Haberdashery, jewelry, smoking, snuffing and quid devices
45: Agriculture and forestry, gardening, viticulture and fruit cultivation, dairy, animal breeding and care, animal catching and destruction, hoof shoeing
45K Pest control, animal capture, hunting equipment
45L Animal and plant preservation, chemical agents for animal and plant destruction
46: Internal combustion engines, compressed air, spring power and other power machines
46A Internal combustion piston engines, general
47: Machine elements
48: Chemical surface treatment of metals
48A Electroplating: electroplating, electroplating, electrical metal etching
48B Metal plating: gold plating, tin plating, galvanizing etc. except electroplating
48C Enamelling, glazing of metals
48D Chemical surface treatment of metals and corrosion protection of metals
49: Metalworking, mechanical (sheet metal, tube and wire processing, rolling mills 7)
50: Grinding and crushing including preparation for grinding, post-treatment of the ground material by sifting and mixing as well as separation of the grinding dust from the used air
51: Musical instruments
52: Sewing and embroidery
53: Food and beverages, as long as they are not listed in special classes, including animal feed
53C Preservation of animal and plant foods, unless listed in 53d-f and h-k. Artificial ripening of fruit; processing of grain; chemical peeling processes for grain; Natural and artificial casings, chemical part
53D Coffee, coffee substitutes, tea, tea substitutes
53E Preserving milk, milk preparations, dairy, chemical part
53F Cocoa, chocolate and confectionery
53G Feed and feed steamer
53H Margarine and cooking fats
53I Proteins, phosphatides and preparations containing these substances
53K Manufacture and preparation of food, insofar as it is not specified in 53 c-i
54: Paper and cardboard processing and products, as far as their production is concerned, as well as advertising
55: Pulp, paper and cardboard production
55B Process for the production of pulp, pulp digester, recovery of waste liquor and exhaust gases
55C Bleaching, sizing, dyeing, filling, weighting of paper pulp and pulp, Dutchmen, cloth mills, pulp pulpers
56: Upholstery and saddlery
57: Photography, cinematography and sound film
57A Photographic cameras with accessories, lens shutters, cinematographic apparatus, automatic photographic machines, sound film machines
57B Photographic processes, blueprints, photosensitive plates and papers, color photography, X-ray photography, photosculpture
57C Equipment and machines, darkrooms
57D Photomechanical reproduction
58: Presses
59: Liquid pumps, liquid actuators and other liquid lifting devices
60: Regulators for engines
61: Rescue and fire extinguishing services
61A Devices for rescue from fire hazards and for rescuing those who appear to be dead; fire extinguishing; respiratory protection; Protection against chemical warfare agents
61B Chemical repellents and protective agents against warfare agents, chemical compositions for respiratory protective devices; chemical fire retardants and processes
62: Aviation
63: Trackless vehicles
64: Bars
65: Shipbuilding and seafaring
66: Butchery and meat processing
67: Grinding and polishing
68: Locksmith products
69: Cutting tools, including cutting and stabbing weapons
70: Writing and drawing instruments
71: Footwear and its manufacture
72: Firearms, bullets, entrenchments
73: Rope making
74: Signaling
75: Sculpture, painting, surface decoration
76: Spinning
77: Sports, games, toys, popular entertainment
78: Ignition production, explosives, blasting using explosives, fireworks, flashlights, production of artificial fog
78B Match making, chemical part
78C Manufacture of gunpowder and explosives as well as processes and devices for their mechanical processing
78D Fireworks sets, smoke generators, fog generation, flash lights
78E Explosive process, ignition of explosive shots, explosive cartridges
78F Chemical and pneumatic lighters; Ignition bands, chem. part; pyrophoric metals and alloys
79: Tobacco, cigars, cigarettes
79C Tobacco, cigars and cigarettes, chemical part
80: Pottery, stones, lime, cement, plaster, asphalt, also briquette presses
80B Mortar mixtures, ceramic masses, production of artificial stones insofar as it relates to the mass, glazes
81: Transport and packaging
82: Drying, also kiln, coffee burner, spin dryer (for general use)
83: Clocks and timekeeping
84: Hydraulic and foundation engineering, dredging work
85: Mineral and fizzy water, water purification, water supply and sewerage
85A Mineral and fizzy water
85B Purification of water
85C Wastewater treatment
86: Weaving
87: Tools and work equipment, including pneumatic tools, for general use
88: Wind and water power machines
89: Sugar and starch production
89C Juice extraction from sugar beets, sugar cane and the like; Purification of sugar juices and sugar solutions
89D Cane sugar and consumer sugar work, including evaporation and boiling
89H Molasses desugarization
89I Starch sugar, invert sugar, lactose, syrup and maltose
89K Starch and dextrin

Notes: In bold: technology areas, complete list. Below technology areas, the table lists technology classes included in the baseline sample. Technology areas without listed technology areas are not included.