

Coordination and Collusion in Industrial Development

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Abstract

Can organizations that sustain collusion also promote growth? We study German industrialization, when the country reached the technological frontier and legally enforceable cartels came to organize more than half of industrial output. We link the universe of cartel contracts and court rulings on their enforceability to annual data on all joint-stock firms, input-output linkages, and censuses before 1933. Our model formalizes a trade-off between the static losses from market power and the investment gains that cartel rents may support under financial frictions. Vertical contracts between cartels and their buyers can reduce these losses. To estimate these effects, we use staggered cartel entry and unexpected changes in cartel enforceability. Cartel members earned more, invested more, upgraded, and scaled up, especially in capital-intensive industries. Upstream cartelization initially lowered downstream performance, but this effect diminished as vertical contracts, facilitated by banks and the state, expanded. Districts with more cartel members recorded higher employment, while markets with a higher cartel share saw fewer entrants and greater concentration. The results suggest that organizations sustaining market power can finance investment when financial markets are incomplete; the cost is a market structure that favors incumbents over entrants.

Keywords: cartels; industrialization; contracts; investment; financial frictions

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The nation must sacrifice and forgo material goods; it must sacrifice present advantages in order to secure future ones. ... The tree that bears the fruit is more valuable than the fruit itself.

Friedrich List, *The National System of Political Economy* (1841)

1 Introduction

Rapid industrialization often coincides with the rise of cartels and conglomerates. Do these arrangements hinder development by restricting competition and entry, or promote it by letting constrained firms retain and invest rents? We study this question across the production network by combining new data on German industrialization with a model of market power and development. We observe the whole system of contracting, among competitors and with their buyers, and link it to investment, entry, and concentration.

Germany provides a canonical setting for this analysis. As the last major Western power to industrialize, it remained dependent on cheap labor and the imitation of foreign technology into the 1890s. By 1913, however, Germany had reached the technological frontier, become a major exporter, and achieved global leadership in chemicals and electrical engineering, creating the industrial base for two world wars (Veblen, 1915; Gerschenkron, 1962). Over the same period, cartels became a defining feature of German industry, coordinating prices or output among competing firms through enforceable contracts, usually organized by product and region. After an unexpected court decision affirmed the legal enforceability of early agreements, cartelization spread rapidly. By 1930, cartels organized more than half of industrial output (Chandler, 1990). Germany thus combined export- and innovation-led development with cartel-based industrial organization, a model that became influential abroad and shaped later episodes of rapid catch-up growth (Johnson, 1982; Amsden, 1989).

To assess whether cartels promoted, hindered, or merely accompanied industrialization, we construct a new annual panel linking all 27,109 joint-stock firms to the universe of 3,806 cartel contracts between 1882 and 1933. Digitized archival sources allow us to track cartel membership alongside firm-level measures of investment, upgrading, and expansion, as well as confidential records of war mobilization. We measure effects beyond cartel members by combining input-output linkages, cross-sector agreements, and county-industry data from five industrial censuses.

We study the horizontal and vertical consequences of cartels in three steps. We begin with the chemicals industry, focusing on the development of synthetic nitrogen fertilizer in the early twentieth century. Today, this technology is estimated to sustain more than half of the world population. The setting offers unusually detailed evidence: corporate accounts record financing and investment, while product-level records link firm decisions to capacity and prices. After a profit-sharing agreement among three chemical firms in 1905, retained earnings financed major investments in nitrogen capacity. Patenting increased, and the subsequent technological breakthrough and scale-up reduced fixed-nitrogen prices and displaced natural nitrate in world markets. The importance of internal finance increased when external trade and finance tightened during the First World War. Agreements with agricultural buyers passed part of these gains downstream while preserving upstream rents.

Second, we formalize this mechanism in a dynamic model of market power with financing frictions. Industrial upgrading requires large, long-horizon investments where external finance is often limited (Hirschman, 1958; Tilly, 1982). Our model centers on financial frictions as a core obstacle to development. Firms must finance upfront working capital for cost-reducing investment but face a borrowing constraint. Collusion in output markets can relax this constraint by expanding internal financing capacity, but it also induces output distortions. Market power thus creates a dynamic trade-off between financing productivity growth and imposing static losses (Williamson, 1968). The model predicts that cartel enforcement can raise output when financial constraints bind, investment opportunities are strong, and downstream costs are limited. We also characterize vertical agreements that reduce these output distortions while preserving the financing benefits of cartel rents.

Third, we test the implications of the framework in the broader panel across firm-level, downstream, and aggregate margins. At the firm level, we follow the chain from earnings to investment, upgrading, and scale: earnings are measured by revenue; investment by reserves, capital, and capital expenditure; upgrading by patenting and exporting (Griliches, 1990; Melitz, 2003); and scale by production and employment (Lucas, 1978; Sutton, 1997). We then test for changes in dividends, changes in board ties to firms, banks, the state, and science, and heterogeneity by industry financing constraints and investment opportunities. We assess whether the same financing mechanism supported strategically valuable production during the First World War through military

procurement, military innovation, and wartime production coordination (Howell et al., 2025). We then trace effects through the production network, estimating whether upstream cartel exposure affected the same outcomes and whether cross-sector agreements mitigated the effects. At the aggregate level, we examine district employment, firm entry and exit, and concentration.

Cartel formation was not random. Our empirical strategy therefore uses variation in cartelization across products, regions, and time created by Germany’s economic and legal fragmentation. This setting supports two complementary designs. The first design uses the full variation in the timing of cartel entry across firms and markets. Despite growing global integration, German product markets remained geographically segmented (Wolf, 2009), while cartel organization varied widely across industries and regions (Guinnane, 2020).¹ We document substantial geographic variation in membership and modest observable differences before entry: across predetermined firm, geographic, and industry characteristics, eventual members closely resembled firms that never entered a cartel.

Our baseline specification compares changes within firms at cartel entry with contemporaneous changes among nonmembers. We complement a difference-in-differences specification with firm and year fixed effects by using event studies to trace outcome dynamics before and after entry.

We organize the robustness analysis around four concerns. First, we address potential selection into cartels with flexible controls, matching, and reweighting. Second, we account for industry- and region-specific shocks that may have coincided with cartel formation. Third, we address spillovers to nonmembers that could contaminate the comparison group. Finally, we show robustness to alternative estimators, samples, and definitions of treatment and outcomes.

Our second empirical design uses a discrete change in legal enforceability. At the beginning of our period, whether cartel agreements could be enforced against their members was highly uncertain. This changed abruptly in 1897, when the Imperial Court upheld cartel enforceability in a landmark case. The decision was widely viewed as consequential and difficult to anticipate; contemporaries described the ensuing spread of cartels as arriving “like lightning” (Schäffle, 1898). Our data show a discrete increase in cartel formation after the ruling.²

¹With reference to 1913, Wolf (2009) notes that “trade districts within Germany were no better integrated than districts on opposite sides of the borders.”

²The decision arose from litigation involving a small wood-pulp cartel and helped establish freedom of contract as a basis for enforcing cartel agreements. Its importance was reinforced by the broader consolidation of German private law during this period, which drew disproportionately from the law of the wood-pulp cartel region.

The ruling’s reach varied across sectors and across the map. Each cartel case reached the Imperial Court in a specific sector, and each senate of the court heard appeals from a fixed set of private-law regions.³ We accumulate the pro-cartel decisions of the court through 1914 as shifts: a decision loads on a firm when it concerns the firm’s sector, weighted by the deciding senate’s share of cartel cases arising from the firm’s private-law region. The instrument is the sum of these weighted rulings to each year. Recentered versions subtract the same object built from the non-cartel business rulings, or keep only the decisions that overturned the lower court — the surprise component.

Relevance requires that cartel membership rose more where pro-cartel rulings accumulated in a firm’s sector and body of law. In a specification with firm and year fixed effects, the accumulated rulings predict cartel membership with a first-stage F -statistic of 28.1 for exporting and patenting.

Identification draws on both components of the instrument. The shares, which law regions a senate heard, were fixed by the organization of the court rather than by the outcomes of firms; the shifts, the order in which sectors’ cases reached the court and under which law, must be unrelated to the outcome trends of those sectors except through enforceability (Goldsmith-Pinkham et al., 2020; Borusyak et al., 2022). The estimates for exporting and patenting hold within districts split by a law border, with the instrument recentered on the non-cartel business rulings of the court, and with only the rulings that overturned the lower court.⁴

Together, the two designs examine complementary variation. The baseline uses realized cartel entry across firms, markets, and years. The shift-share design isolates the variation generated as enforceability accumulated in a firm’s sector and body of law, anchored by the unanticipated ruling of 1897.

We organize our findings around the three margins emphasized by the framework. At the firm level, cartelization was followed by both upgrading and expansion. Among cartel members, the probability of patenting increased by 0.02 relative to the pre-entry period, against a baseline mean of 0.05; the probability of exporting increased by 0.06, against a mean of 0.07. Output rose by about 13 percent, employment by 8 percent, and capital by 31 percent. These differences appeared after entry and persisted, with no discernible pre-entry trends across outcomes. The shift-share

³Contemporaries emphasized the heterogeneity of early cartel organization and enforcement (Reichsministerium des Innern, 1906; Silberberg, 1910; Wagenführ, 1931).

⁴The estimates remain similar when varying the level of clustering across markets and legal regions.

instrument supports these patterns.

After cartel entry, average investment rose by about 22 percent, retained earnings by about 20 percent, and profit by about 4 percent, while dividends did not rise. This suggests that cartel members retained and invested the additional rents rather than paying them out. Their boards also acquired more interlocking directors and more directors tied to the state, banks, and research institutions. Expansion was substantially larger in capital-intensive industries, where outlays were large and external finance scarce. Consistent with the strategic value of internal finance under wartime constraints, declassified records from the First World War show that cartel membership was associated with a 0.04 increase in the probability of holding a military procurement contract, against a mean of 0.12; a similar pattern holds for secret war patents and seats on wartime production boards. These financing and organizational responses are consistent with the model.

Upstream cartelization was initially associated with lower activity among downstream buyers. Where cartelized inputs were not governed by a cross-sector agreement, higher exposure was associated with lower output and employment. Where an agreement governed the link, the associations were positive for output and employment. These agreements spread through the state-backed negotiations of 1904, and the pattern is consistent with historical accounts and the model prediction that vertical contracting can preserve upstream rents while mitigating downstream distortions.

At the aggregate level, districts with more cartel-member firms recorded higher employment across five industrial censuses between 1882 and 1933. A descriptive decomposition attributes 27% of the observed growth in district industrial employment to growth among cartel-member firms. This expansion came with costs to market structure: markets with a higher cartel share recorded fewer entrants and exits, greater incumbent survival, and higher concentration.

Our findings highlight the trade-off at the center of the framework. In the context of Germany, cartelization coincided with greater investment and development where financing constraints were more likely to bind; vertical agreements attenuated downstream distortions. The cost operated through the future structure of markets: expansion favored established producers over new entrants.

Related literature. The idea that profits generated along an “optimal chain of disequilibria” can spur investment has long been central to theories of late development (Lewis, 1954; Hirschman, 1958; Amsden, 1989; Amsden and Singh, 1994; Acemoglu et al., 2006).⁵ We provide firm-level evidence on this mechanism in a canonical setting, revisiting early work on German cartels and financial constraints (Kuznets, 1930; Kaldor, 1935; Dixit and Pindyck, 1994).⁶ Our mechanism thus relates to research on financial frictions, in which costly external finance ties investment to retained earnings.⁷ Cartel enforceability can therefore be understood as a commitment device that relaxes financial frictions (Holmström and Tirole, 1997).⁸ Closest to our model are Itskhoki and Moll (2019), who study redistribution toward constrained producers through Ramsey-optimal taxation. In our setting, resources are instead transferred indirectly, through product-market rents.⁹

⁵The relationship between market power and capitalist development has long been contested (Braudel, 1984). One line of work treats scale and coordination as prerequisites for industrial development and competitiveness (Hamilton, 1791; Draghi, 2024; Dunkelman, 2025). Another emphasizes the risks of collusion, barriers to entry, weakened self-government, policy distortions, and regulatory capture (Jefferson, 1785; Brandeis, 1934; Bhagwati, 1969; Stigler, 1971; Krueger, 1990; Cole and Ohanian, 2004), warning that producer meetings tend toward “a conspiracy against the public, or in some contrivance to raise prices” (Smith, 1776).

⁶Contemporaries framed the problem as “ruinous competition”; formal treatments of destructive competition include Edgeworth (1925), Taussig (1911), Brandeis (1913), Clark (1923), Maskin and Tirole (1988), Telser (1994), and Caballero and Hammour (1994). Contemporary observers extensively documented individual German cartels such as the steel syndicate (Walker, 1906), the potash syndicate (Tosdal, 1913), and wartime cartels (Notz, 1915; Kronstein, 1942; Klein, 1948; Newman, 1948). Broader English-language accounts of the German cartel system are Stockder (1924), Bloch (1932), and Levy (1935). The larger German-language literature is reviewed, for example, in Tschierschky (1928), building on Kleinwächter (1883), Braun (1892), Schmoller (1894), Liefmann (1903), and Baumgarten and Meszlény (1906).

⁷See Stiglitz and Weiss (1981), Greenwald and Stiglitz (1986), Fazzari et al. (1988), Aragonese et al. (2026), and Basante Pereira and Simonovska (2026). These frictions misallocate capital and lower productivity (Galor and Zeira, 1993; Olley and Pakes, 1996; Chari et al., 2007; Restuccia and Rogerson, 2008; Hsieh and Klenow, 2009; Moll, 2014; Bau and Matray, 2023; Quincy and Xu, 2025; Ghatak and Mookherjee, 2025; Bai et al., 2026), especially in capital-intensive sectors and during the adoption of more productive technologies (Buera et al., 2011; Buera et al., 2013; Midrigan and Xu, 2014; Aghion et al., 2026). We show how product-market rents can finance dynamic investment gains at the cost of static output losses, paralleling the “paragons or parasites” view of business groups (Khanna and Yafeh, 2007). A parallel debate in development policy asks whether scarce finance should support microenterprises or large firms and business groups (Banerjee et al., 2015; Meager, 2019; Ciani et al., 2020). The role of Nigerian conglomerates in industrial policy is a recent case (Itaman and Wolf, 2021). In a dynamic oligopoly, collusive profits that fund investment and entry can likewise raise consumer surplus, even though prices are higher in any given period (Fershtman and Pakes, 2000), or can finance coordinated investments (d’Aspremont and Jacquemin, 1988; Gross, 2020). Internal finance has mattered across periods and settings. Retained earnings were central to the first Industrial Revolution (Ventura and Voth, 2015), remained important in Germany into the second half of the twentieth century (Tilly, 1980), and financed more than half of enterprise investment in China, especially in new technologies, into the mid-2000s (Kuijs et al., 2005; Song et al., 2011). Recent Chinese debates over “involution-style” competition likewise reflect concern that persistent price competition and compressed margins may weaken investment capacity (State Council of the People’s Republic of China, 2025; Ju Li, 2025). From a theoretical perspective, this is consistent with a shift from price to quality competition resting on sunk outlays, and thus being accompanied by greater concentration (Sutton, 1991; 1998).

⁸Our finding that bank board ties deepened only after cartelization is consistent with risk-averse lenders supporting large investments once returns became more secure (Bernanke, 1983; Petersen and Rajan, 1995). German investment has traditionally been attributed to coordination by the great banks (Jeidels, 1905; Riesser, 1911; Tilly, 1982; De Long, 1991), although this interpretation has been contested (Fohlin, 2005; Burhop, 2006). The post-cartelization deepening of bank ties also recalls the argument that cartels helped fuse banking and industry into “finance capital” (Hilferding, 1910).

⁹A related equivalence between market power and a uniform output tax is derived in Edmond et al. (2023).

Despite their historical prevalence, cartels have received less attention as instruments of industrial policy (Johnson, 1982; Juhász and Steinwender, 2024).¹⁰ We characterize two trade-offs inherent in the developmental implications of cartel policy. First, compared with taxes, subsidies, and tariffs, cartel enforceability requires little direct state expenditure, instead transferring resources to upstream firms through product-market rents. Our results highlight that this comes at a cost: cartels may also favor incumbents and distort downstream production.¹¹ Second, delegating self-governance to cartels limits the costs of eliciting information from firms, an obstacle that has been identified as central to development (Green and Laffont, 1977; Evans, 1995; Rodrik, 1995; 2004).¹² Cartel enforceability thereby operated as delegated policy: the state set and enforced bounds on admissible conduct, leaving better-informed firms to write agreements between themselves (Holmström, 1984; Alonso and Matouschek, 2008; Amador and Bagwell, 2013).¹³ This, however, gives the state less control over which firms receive support and how funds are used, a trade-off familiar from delegation to nonelected officials (Epstein and O'Halloran, 1999; Maskin and Tirole, 2004; Alesina and Tabellini, 2007).¹⁴ The trade-offs inherent in these instruments are

¹⁰Production, investment, and entry subsidies have recently been studied in Criscuolo et al. (2019), Kim et al. (2021), Choi and Shim (2024), and Lane (2025); trade protection in Bartelme et al. (2025); and export-credit subsidies in Matray et al. (2026). For overviews of this growing literature, see Juhász et al. (2023) and Juhász et al. (2024). In contrast, institutional substitutes for missing prerequisites of development have been emphasized in earlier work (Gerschenkron, 1962; Cheremukhin et al., 2017; 2024). Diversified groups can internalize missing capital, managerial, and product markets and pool project-execution capabilities (Leff, 1978; Amsden and Hikino, 1994), but these advantages must be weighed against entrenchment, tunneling, and weaker competition (La Porta et al., 1999; Morck et al., 2005; Schneider, 2013). Such groups included Japanese *zaibatsu* and postwar *keiretsu*, Korean *chaebol*, Indian managing agencies and business houses, Chinese *qiye jituan*, Indonesian *konglomerat*, Turkish holding companies, and Latin American *grupos económicos*. Their ownership and legal structures differed, but each coordinated finance, production, and investment across affiliated firms. Cartels instead coordinated independent producers by contract. Japan combined both forms, authorizing or tolerating several types of cartels alongside its business groups (Tilton, 1996; Schaede, 2000). Across these settings, cartels emerge as corporatist organizations (Schmitter, 1974). In Germany, this lens has more often been applied to labor relations and codetermination than to producer coordination (Jäger et al., 2021). In its early stages of development, Germany also used tariffs, railways, and public investment in scientific and technical education. Protective tariffs were introduced from 1876 (Webb, 1980; Torp, 2010); on protection in the presence of scale economies and learning, see P. R. Krugman (1984), Brander and Spencer (1985), P. Krugman (1987), Young (1991), Gaubert and Itskhoki (2021), and Gaubert et al. (2021). Railway expansion and technical education provided complementary forms of support (Murmann, 2003; Braun and Franke, 2022; Chiopris, 2024).

¹¹In this respect, cartel protection resembles patent protection: both finance firms through product-market rents rather than direct transfers. Patent rents accrue only after success and thereby reduce selection and moral-hazard problems; unlike cartel rents, however, they still depend on financial markets (Wright, 1983; Green and Scotchmer, 1995; Lerner and Tirole, 2004).

¹²Classic rationales for centralized intervention include coordination failures across complementary investments (Scitovsky, 1954; Murphy et al., 1989; Rodrik, 1996; Garg, 2025) and learning by doing (Asmat, 2021; Barwick, Kalouptsi, Lee, et al., 2025).

¹³A class of models of delegation studies a principal who cannot elicit private information and grants a better-informed agent discretion over a restricted set of actions (Holmström, 1984; Alonso and Matouschek, 2008); a cap on admissible conduct parallels the tariff caps studied by Amador and Bagwell (2013). Public enforcement backing private rule-setting in turn parallels government oversight of industry self-regulation (DeMarzo et al., 2005).

¹⁴A related trade-off arises between central direction and local adaptation (Luo et al., 2025). Tariffs economize on

especially salient in strategic inputs and basic industries: directing resources upstream may also build geopolitical capacity.¹⁵ War made strategic inputs effectively non-tradable, the case in which coordination failures bind most (Rodrik, 1995); blockade episodes redirect technology adoption (Juhász, 2018). The political economy of such coordination is documented across settings: market power distorted democracy in the Progressive Era (Scheve et al., 2024), political connections carried value under National Socialism (Ferguson and Voth, 2008), heavy-industry promotion in South Korea was tied to defense industrialization (Kwon, 2018; 2020), and military procurement shaped the direction of innovation (Howell et al., 2025). More broadly, the choice among policy instruments is itself institutional, often resulting in second-best implementations (Lipsey and Lancaster, 1956; Djankov et al., 2003).

Finally, we provide quasi-experimental evidence on the long-run effects of cartels on market development. Cartelization expanded incumbent firms but generated little entry, increasing concentration (Mankiw and Whinston, 1986; Autor et al., 2020; De Loecker et al., 2020; Kwon et al., 2024; Starc and Wollmann, 2025).¹⁶ It also affected innovation and exporting across a broad range of firms and sectors, linking our results to research on competition, innovation, and trade (Hicks, 1935; Schumpeter, 1942; Arrow, 1962; Aghion et al., 2005; Melitz and Ottaviano, 2008).¹⁷ The

fiscal capacity but may be poorly suited to targeting upstream sectors in export-oriented economies (Antràs et al., 2024); for the rationale for upstream targeting, see Liu (2019). In addition to the substantial information and administrative capacity required to target support effectively (Hayek, 1945; Pack and Saggi, 2006; Barwick, Kalouptsi, and Zahur, 2025), selective support can also invite capture and rent-seeking (Grossman and Helpman, 1994) and thus might be disfavored relative to uniform instruments or the absence of policy (Panagariya and Rodrik, 1993; Aghion et al., 2015). In our setting, state–industry ties reflected co-dependency as well as capture: the state enforced cartel agreements, participated in some cartels, and held seats on cartel boards, while firms could shape policies. This coordination was reinforced by interlocking directorates and ties to banks and the state, overlapping links that can soften competition (Dal Bó and Di Tella, 2003; Azar et al., 2018). Under National Socialism, these links were repurposed into a command economy (Neumann, 1944). More broadly, such a feedback between market and political power might be bounded (Cowgill et al., 2024; Callander et al., 2022; Grotteria, 2024; Scheve et al., 2024).

¹⁵Contemporary support for strategic upstream sectors, including semiconductors under the CHIPS and Science Act (United States Congress, 2022), the green transition, and critical minerals (Clayton et al., 2025; Domínguez-Iino et al., 2026), relies mainly on direct subsidies, whereas our setting shows how market power can serve as an alternative when subsidies are unavailable. Allied decartelization after 1945 reflects the military importance attached to that capacity: the combinations were dismantled partly to weaken German industrial and military power (Borkin, 1978; Crane, 2023). For German business under war and dictatorship, see Feldman (1966), Hayes (1987), and Ferguson and Voth (2008).

¹⁶Concentration can also move production toward more efficient producers. Several cartels allowed members to trade production quotas, so that efficient firms could buy and retire the quotas of less efficient ones. In U.S. power generation, high-productivity firms acquire underperforming plants and raise their efficiency (Demirer and Karaduman, 2026). On the efficiency and distributional effects of consolidation, see also Prager and Schmitt (2021), Montag (2025), Das et al. (2026), and Metcalfe et al. (2026).

¹⁷A closely related study shows that patent protection raised innovation and downstream productivity in U.S. agriculture, with effects extending from producers to aggregate output (Moscona, 2026). Patent pools of substitute technologies reduced innovation (Lampe and Moser, 2010; 2016), whereas pools of complements can raise it (Lerner and Tirole, 2004); price-fixing cartels have been found to raise member investment and innovation (Kang, 2025). See also Cullen et al. (2025), Adhami (2026), Ma et al. (2026), and Barwick et al. (2026).

downstream estimates relate to empirical work on vertical markets, where negotiated terms govern trade and divide surplus between buyers and sellers (Oi, 1971; Collard-Wexler et al., 2019; Lee et al., 2021; Kroft et al., 2025; Demirer and Rubens, 2026). Because we observe the extensive margin of otherwise clandestine collusion, we can study determinants of cartel formation and stability that are usually latent (Stigler, 1964; Green and Porter, 1984; Rotemberg and Saloner, 1986; Levenstein and Suslow, 2006; Sugaya and Wolitzky, 2018; Igami and Sugaya, 2022; Ortner et al., 2024; Sugaya and Wolitzky, 2026). These contracts also did not need to be self-enforcing: courts collected the fines, so legal enforcement replaced the detection and punishment that sustain collusion in these models. Legal enforceability increased both formation and persistence, consistent with the role of contracts and commitment in development (North, 1990; Greif, 1993; Acemoglu and Johnson, 2005). More broadly, when intertemporal gains are large, organizational forms that bind future conduct can substitute for missing markets (Coase, 1937; Williamson, 1985; Ostrom, 1990; Baker et al., 2002). Cartels were one such form and, more generally, one departure from the benchmark of efficient exchange (Walras, 1874; Bénassy, 1993; Flynn et al., 2026; Jagadeesan and Teytelboym, 2026). We trace the emergence and consequences of a cooperative system of industrial organization associated with German development and later emulated elsewhere (Wade, 1990).¹⁸

2 Institutional Context

We describe the institutional context in three parts: German industrial upgrading and its financing, the rise and legal enforceability of cartels, and a case study of synthetic nitrogen. Appendix B.1 presents additional historical evidence.

2.1 Industrial Upgrading and Financing

Industrial upgrading. Germany approached the industrial frontier as a latecomer. In the mid-nineteenth century, its producers relied heavily on technology “borrowed from English and French sources” (Veblen, 1915). Manufacturers initially competed largely through low-cost imitation of

¹⁸Cartels spread across interwar Europe (Hewitt, 2024). Japanese industrial policy later drew on German institutional experience, particularly proposals for industrial organization made during the First World War (Rathenau, 1918; Pyle, 1974; Mimura, 2011); those proposals also became a reference point for revolutionary planning in Russia (Lenin, 1917).

established products.¹⁹

By the early twentieth century, German competition had changed markedly. Firms held strong positions in chemicals, electrical engineering, machinery, steel, optics, and shipbuilding, supported by major improvements in product quality and proprietary technology. British policy increasingly responded not to imitation but to Germany's emergence as a technological and industrial rival.²⁰ Observers warned of a "deliberate and deadly rivalry" for industrial supremacy (Williams, 1896). By 1913, Germany was the leading industrial economy on the European continent and was approaching Britain in world export markets, with particular strength in advanced sectors (Chandler, 1990; Hesse, 2023).

Capital requirements. Reaching the technological frontier required large and sustained capital expenditures (Chandler, 2005). Firms had to finance both technological development and entry into foreign markets.

German firms invested heavily in industrial experimentation, process development, and commercialization, building close links with universities and fundamental research.²¹ German scientists won a large share of early Nobel Prizes, especially in chemistry, where many laureates conducted research within or in close connection with industrial firms (Appendix Figure A.1). Capital thus helped connect scientific research to industrial application.

Exporting imposed a second financing demand. Reaching foreign markets required substantial commercial and organizational investment, especially for more sophisticated products. Foreign market entry was therefore itself capital intensive.²²

Technological development and export expansion also had strategic consequences. Innovation created dual-use capabilities, while export success made foreign buyers more dependent on German supply.²³ Industrial upgrading therefore increased both Germany's productive capacity and

¹⁹The British Merchandise Marks Act of 1887, for example, responded to concerns that imported goods could be mistaken for domestic products by requiring foreign origin to be identified in such cases; "Made in Germany" consequently became a warning label attached to German manufactures (Payn, 1888).

²⁰Drafted in response to German competition, the British Patents and Designs Act of 1907 required foreign patentees to work their patents domestically or risk revocation absent adequate justification.

²¹As frontier research became increasingly capital-intensive, the late nineteenth century saw the "industrialization of invention" (Meyer-Thurow, 1982).

²²Greater product sophistication, including maintenance and servicing requirements, also encouraged joint ventures and direct investment rather than reliance on exports alone.

²³British observers, for example, raised concerns about reliance on German chemical inputs such as potash and saltpeter (Williams, 1896).

its strategic importance abroad.²⁴

Internal finance. Germany's rapid industrial ascent occurred amid persistent financial frictions. Equity markets were fragmented, new issues could dilute control, and bank lending was limited by monitoring and collateral requirements (Tilly, 1982). Retained earnings therefore became an important source of investment finance. In the chemical industry before 1900, internal operating surpluses financed more than half of expansion (Prion, 1931); contemporary evidence points to similar retention practices elsewhere in German industry.²⁵ This reliance persisted as firms approached the frontier. The First World War tightened financing constraints: government war-bond issues absorbed private savings and crowded firms out of the long-term capital market; new share issuance and the discounting of trade bills collapsed; the stock exchange closed; and firms lost access to foreign capital and currency. Internal funds financed the conversion to war production. Walther Rathenau of AEG told the 1915 general meeting that shareholders could not have been asked to risk 30 or 40 million marks on war contracts of uncertain outcome; industry instead financed the conversion from its silent reserves (Tschierschky and Borger, 1915, p. 913). The state relied on the same organized structures: the wartime raw-materials administration designed by Rathenau allocated inputs through war corporations run by industrialists (Rathenau, 1918; Feldman, 1966). After the war, disruption and inflation left liquid capital scarce (Whale, 1930; Brunnermeier et al., 2025).²⁶ Retained earnings thus expanded firms' investment capacity.

2.2 Cartels, Legal Enforceability, and Downstream Bargaining

Cartels. Reliance on retained earnings sat uneasily with the competitive environment of German industry under the imperial trade code of 1869 (Pierenkemper, 2007). Contemporaries increasingly described pressure on prices and margins as "ruinous competition," often linking it to excess ca-

²⁴As foreign governments came to regard these industries as strategically important, restrictions on patents, imports, and market access could further raise the cost of serving foreign markets. The British patent-working requirement of 1907 and later trade barriers, including the Dyestuffs Act of 1920 and the Safeguarding of Industries Act of 1921, reinforced this shift.

²⁵One Rhenish ironworks, for example, made it a rule to pay no dividend above 5 percent regardless of earnings, placing the remainder in reserve and investment funds (Williams, 1896).

²⁶The importance of self-financing persisted well beyond our period of analysis: between 1954 and 1968, internal funds financed roughly 80 percent of gross investment (Tilly, 1980).

capacity and contrasting it with stabilization (Schmoller, 1894).²⁷ Margin compression also reduced the resources available for investment.

Cartels provided a contractual mechanism for limiting competitive pressure. A cartel coordinated prices, output, or sales among otherwise independent firms.²⁸ Early arrangements were modest: local coal and salt syndicates coordinated terms through ad hoc contracts (Marburg, 1964).

Variation and legal enforceability. Cartel organization varied substantially along three dimensions: across products and regions, across legal forms, and over time in enforceability. First, agreements were typically organized by product and region, reflecting markets deeply segmented by transport costs, commercial practice, and the legacy of separate states (Liefmann, 1905; Wolf, 2009).

The legal environment provided a second source of variation. No general cartel law existed, so agreements fell under a patchwork of contract, association, and other private-law rules that differed across regions and organizational forms (Langhorst, 1926; Nörr, 1994). Private law itself varied territorially; codification unified much of private law in 1900, and association law remained regionally specific until it too was harmonized in 1908, with *de facto* differences persisting much longer (Zeller, 1895; Guinnane, 2020).

Third, enforceability changed over time through discrete and often unexpected shifts. Through the 1880s, cartels relied largely on voluntary adherence and mutual interest, and members who violated quotas were seldom compelled to comply (Kestner, 1912). Early Imperial Court decisions suggested that collective restraints on price undercutting could be consistent with freedom of trade, but the scope of enforceability remained uncertain.

A more decisive break occurred in 1897, in a dispute among Saxon wood-pulp producers. Their cartel was an unincorporated association that assigned each member a production quota and required all output to be sold through a joint sales office (*Verkaufsstelle*); a member who sold outside it owed a contractual penalty of thirty marks per ton. When one member sold on its own account, the cartel sued to collect the penalty. The member argued that the penalty was void, invoking the guarantee of freedom of trade in the imperial trade code (§152), which had until then been read

²⁷Related arguments appear in Kuznets (1930) and Kaldor (1935). More recent arguments that firm coordination can stabilize investment over the business cycle include Caballero and Simsek (2013).

²⁸We follow the contemporary definition of a cartel as an “association between independent firms of the same industry, formed for the purpose of market influence” (Liefmann, 1905, p. 9). Unlike merger, cartelization coordinated market conduct while preserving separate ownership and control.

to leave such restraints unenforceable. Reversing the lower court, the Imperial Court rejected this defense. This marked a departure from the court's earlier treatment of such restraints: freedom of contract allowed firms to bind their own commercial conduct, so the penalty was valid and enforceable (Nörr, 1994). The ruling thus placed freedom of contract above an unrestricted freedom to compete, and it made the exclusive-sales obligation of a joint sales office something a court would uphold. Contemporaries described the subsequent spread of cartels as proceeding "like lightning" (Schäffle, 1898).

Subsequent decisions altered enforceability unevenly. Courts revisited penalties and boycotts, withdrawal rights, and regional association statutes, sometimes overturning prior interpretations (Langhorst, 1926).²⁹ Enforceability therefore advanced through discrete legal shifts rather than a smooth process of convergence.

The Cartel Decree of 1923 marked another institutional break. It created a specialized Cartel Court and introduced the first general rules governing cartel conduct (Goldbaum, 1924). Although formally directed against the misuse of economic power, the decree primarily institutionalized cartel contracting by requiring written agreements and creating a dedicated forum for disputes. Cartel agreements continued largely to be upheld (Langhorst, 1926). Some firms moved toward tighter coordination through *Interessengemeinschaften* (communities of interest), which combined operations and divided earnings while stopping short of full merger (Friedländer, 1921).³⁰

Downstream bargaining. Upstream coordination also created scope for mutually beneficial bargaining with downstream industries. Downstream producers sought relief from cartel input prices, while cartels could expand sales if additional output did not undermine coordinated prices. Negotiations often produced nonlinear pricing: high posted prices combined with rebates or discounts tied to use, destination, or additional purchases. These terms approximate a two-part tariff. Rebates lower the price of additional units and expand sales, while the posted price preserves

²⁹The Imperial Court assessed cartels case by case rather than under a general rule. This includes a large number of unexpected reversals relative to lower courts: Kiel (Tschierschky and Borger, 1910, p. 36f.), Cologne (Tschierschky and Borger, 1911, p. 39), Düsseldorf (Tschierschky and Borger, 1911, p. 41), Hamm (Tschierschky and Borger, 1912, p. 62), and Rostock (Tschierschky and Borger, 1914, p. 243).

³⁰Beyond financing, the contractual form kept open two options that a merger would have closed: duplicate capacity and know-how survived the failure of any one member, and the state's threat of dissolving an agreement remained credible, since ending a contract is cheaper than breaking up a merged firm.

cartel rents on inframarginal units.³¹

A decisive change in the stability of these cross-sector agreements came in 1904, when the German Ministry of the Interior organized “adversarial hearings” that brought cartel members and downstream producers into nonbinding negotiations mediated by experts and public officials (Reichsministerium des Innern, 1906). These proceedings increasingly formalized vertical bargaining over pricing terms alongside horizontal coordination within cartels.

Why did courts and public authorities tolerate, and at times facilitate, these horizontal and vertical agreements? Contemporary discussions often presented private “rationalization” as an alternative to both unrestricted competition and direct state administration (Sombart, 1928). Under this approach, firms retained substantial control over coordination, while public authorities enforced agreements and mediated disputes (Langhorst, 1926; Marburg, 1964). This approach also reflected a broader concern with national economic strength: industrial coordination supported domestic productive capacity, which in turn carried strategic value (Gerber, 2001).³² Direct state intervention nevertheless remained exceptional, concentrated above all in the compulsory potash and coal syndicates during the First World War (Tosdal, 1913; Levy, 1935).

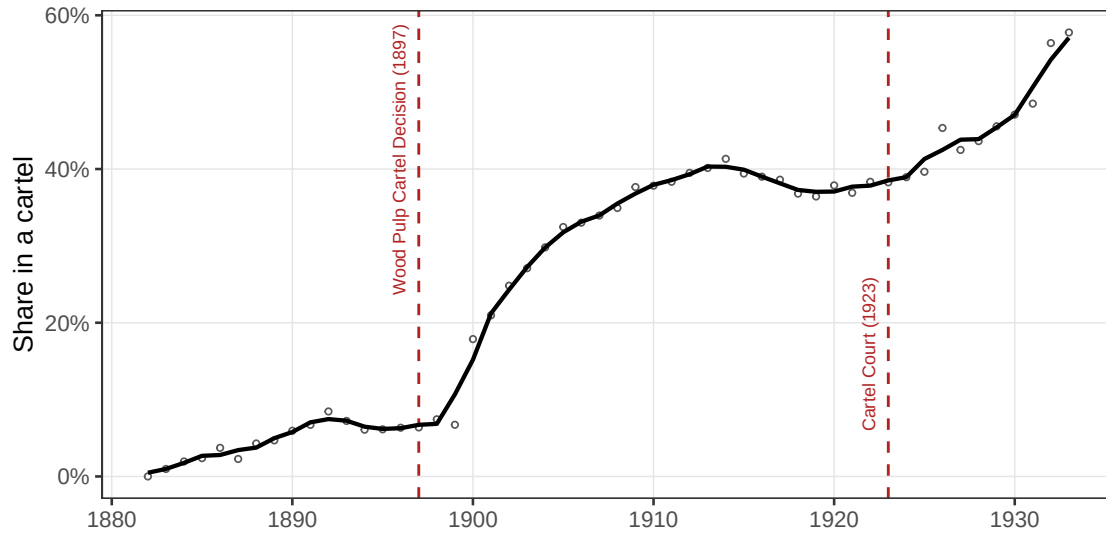
By the 1930s, Germany was widely described as a land of cartels, with more than half of industrial output organized through such arrangements (Chandler, 1990). This broader model of organized industry also became an important reference point abroad.

Figure 1 documents the spread of cartel membership among listed industrial firms. The share belonging to at least one cartel rises from 0% to 57% over the sample period, with pronounced increases around 1900 and in the early 1920s. The series draws on the traded-firm handbook, which covers listed corporations consistently from the 1870s, and is therefore not affected by the entry of the larger unlisted-firm handbook in the late 1890s.

³¹Contemporary observers viewed these arrangements, particularly the export rebates granted by upstream cartels to downstream firms, as an important source of Germany’s export competitiveness. A British commentator wrote: “Thus was forged for all future time the weapon of economic conquest. Thanks to this combination of the cartel and dumping there is not only an avoidance of the danger of backward dumping, ... but by this system of direct or indirect bounties – rebates actually paid or special prices granted to exporters – generalised dumping tends to confer an incontestable superiority on all German industries, to the transformation industries equally with the others.” (Hauser, 1915, p. 106) President Roosevelt later characterized Germany’s cartels as “weapons of economic warfare.”

³²The case for autonomous national productive capacity can be traced to Fichte (1800) and List (1841). In 1891, Chancellor Caprivi explicitly linked expansion of this capacity to the imperative to “export goods” (Torp, 2010). Whether industrialization itself served national strength was contested: Oldenberg (1897) argued that becoming an industrial state left Germany dependent on foreign markets and food, a view Weber (1897) rejected in defending the industrial path.

Figure 1: Cartel Membership among Listed Industrial Firms



Note. Share of listed industrial joint-stock firms that were members of at least one cartel, by year. Industry includes mining, manufacturing, construction, and utilities (NACE industrial sections). The sample consists of firms listed in the traded-firm handbook. Hollow circles denote annual shares; the solid line shows the 2-year moving average. Dashed vertical lines indicate the 1897 wood-pulp cartel decision and the establishment of the Cartel Court in 1923.

2.3 Case Study: Synthetic Nitrogen

We use synthetic nitrogen to trace how German chemical cartels financed a technology with major consequences for agriculture and military production.³³ The resulting technology transformed the world food supply and is estimated to sustain more than half of the world population today (Appendix Figure B.2) (Erisman et al., 2008; Smil, 2011). Nitrogen is essential to plant growth and therefore to food production. Before synthetic fixation, the scarce natural sources of nitrogen constrained agricultural output and population growth. Industrialization and urbanization raised global food demand, and by 1900 agriculture increasingly depended on Chilean saltpeter shipped across the Atlantic, then the principal traded source of fixed nitrogen.³⁴ Nitrogen itself, however, was abundant: it made up about 78 percent of the atmosphere. The difficulty was that atmospheric nitrogen occurs as dinitrogen, N_2 ($N \equiv N$), an exceptionally stable molecule that plants cannot use directly. The Haber–Bosch process fixed this nitrogen by reacting it with hydrogen at extremely high pressures and temperatures in the presence of an iron-based catalyst. It thereby turned the atmosphere into a new source of fertilizer. During the First World War, the same process supplied

³³Appendix B presents additional case studies across chemicals, electrical engineering, iron and steel, coal, and potash. The cases trace both potential dynamic gains from coordination and its static costs, including technological displacement in global markets and losses to consumers.

³⁴Appendix Figure A.2 shows the caliche fields of the Atacama from which that saltpeter came.

nitrogen for explosives. These investments were large, risky, and difficult to finance externally. Vertical agreements with agricultural buyers later passed part of the resulting gains downstream. We trace this episode through corporate accounts, financing records, patents, prices, and production statistics (Figure 2).

The fixed costs of nitrogen investment were financed primarily by retained profits from the firms' coordinated dye businesses. Chemical innovation required large up-front expenditures on laboratories and development, while firms also needed sufficient capital to absorb failed projects (Levy, 1935). These financing requirements made large innovation projects difficult to finance independently.³⁵ BASF, Bayer, and Agfa strengthened their internal financing capacity through the *Dreibund*, concluded in 1904 and in force from 1905, after competition had driven dye prices toward cost (Abelshauser et al., 2004; Plumpe, 2016). The agreement stabilized dye prices above cost and pooled profits in fixed shares: 43 percent each for BASF and Bayer and 14 percent for Agfa (Abelshauser et al., 2004; Plumpe, 2016). The arrangement was formed against the background of increasing legal certainty for cartel contracts. The resulting rents were economically important to the participating firms: dyes accounted for at least 80 percent of BASF's sales through 1904, and often substantially more, during a period historians describe as "the age of dyestuffs" (Abelshauser et al., 2004, sec. I.3). Appendix Figure B.7 plots prices for indigo and aniline around the formation of the cartel. Together with contemporary evidence on profits from protected products, the price series support the interpretation that cartelized dye profits provided an important source of internal finance for nitrogen investment.³⁶

Panel A of Figure 2 plots cumulative investment in the nitrogen program. Documented investment totals 883 million constant 1913 marks, of which 689 million came from cartel-coordinated capital (Appendix Table D.1). These funds financed a stake in Norwegian arc-nitrogen production, a Ruhr colliery that secured energy inputs, and the first full-scale synthetic-nitrogen plants at Oppau and Leuna.³⁷ Scaling these technologies also required coordination with specialized

³⁵In 1903, BASF subscribed only 0.2 million of the 2.0 million kronen offered to it in Sam Eyde's Norwegian arc-nitrogen venture.

³⁶Even alizarin red and alizarin blue, which had been unprofitable for years, became worthwhile "thanks to the convention between the few producing companies" (Duisberg, 1923).

³⁷Three rival nitrogen-fixation technologies competed at the time, and the partners invested in all three, increasing the cost of the program. Electric-arc fixation was associated with Kristian Birkeland, Sam Eyde, and Norsk Hydro; calcium cyanamide with Adolf Frank and Nikodem Caro; and direct ammonia synthesis with Fritz Haber and Robert Le Rossignol, later industrialized by BASF.

suppliers.³⁸

Patent activity expanded alongside the investment program. Panel B of Figure 2 shows that nitrogen-chemistry patents rose from about twenty per year in the 1890s to more than two hundred by the late 1920s. Patent activity accelerated after BASF placed Haber under contract in 1908. By 1912, BASF had transformed the laboratory reaction into an industrial process.

Synthetic production subsequently transformed the world market for fixed nitrogen. Panel C of Figure 2 shows that the real price of contained nitrogen fell by about half by the late 1920s. World synthetic output, initially from coke-oven byproducts and cyanamide, matched Chilean output in 1914 and surpassed it during the war. After falling back to the Chilean level in the postwar collapse, synthetic output resumed its rise after 1922. By 1930, it was three times Chilean output (Panel D). This displacement had severe fiscal consequences for Chile.³⁹ These patterns are consistent with the diffusion of a lower-cost production process.

The First World War made synthetic nitrogen essential to German munitions production. The Allied blockade cut Germany off from Chilean saltpeter, then a critical input into both fertilizer and explosives. Ammonia oxidized into nitric acid provided a domestic substitute (Erisman et al., 2008; Fehr, 2009). In October 1914, BASF promised the War Ministry saltpeter within six months in exchange for a Reich grant of 6 million marks. Wartime expansion extended the same financing model on a larger scale. The German Reich was to provide 199 million marks, BASF 40 million from its own funds, and the combined dye firms 162 million through a two-thirds increase in share capital placed by a bank consortium (Appendix Table D.1) (Abelshauser et al., 2004). In 1918, Oppau and Leuna produced about 90,000 tons of nitrogen, almost all for munitions. The war gave the state a direct stake in synthetic nitrogen production, which it retained when the syndicate formed.⁴⁰

³⁸Retained earnings were only one part of this broader coordination. The partners also coordinated capital issues, guaranteed state loans, and relationships with specialized suppliers. Mannesmann supplied seamless tubes for high-pressure reactors; Krupp developed chromium steels that could withstand the operating conditions; Linde provided gas-separation technology; Griesheim-Elektron supplied hydrogen; and AuerGesellschaft supplied osmium for early catalysts.

³⁹Synthetic nitrogen displaced Chilean nitrate in the world market for fixed nitrogen. Nitrate export duties accounted for nearly half of ordinary government revenue in the two decades before 1914. By 1932, mining-tax revenue had fallen from 28 percent of GDP at its pre-Depression peak to 1 percent (Lüders and Wagner, 2003).

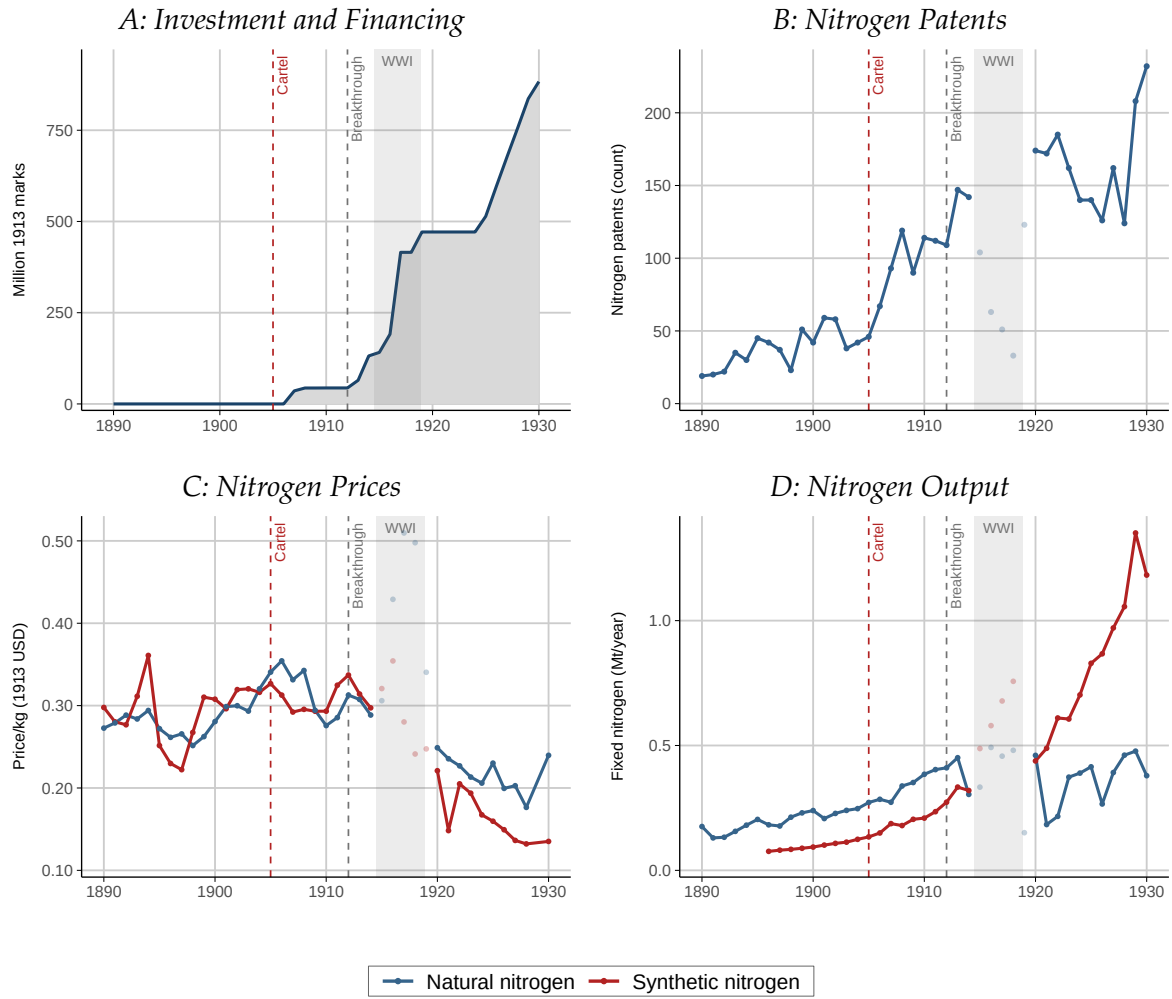
⁴⁰The geopolitical importance of fertilizer inputs was not unique to Germany. The U.S. Guano Islands Act of 1856 authorized the President to annex unclaimed islands containing guano after their discovery and occupation by U.S. citizens. The Supreme Court upheld this authority in 1890, and U.S. law continues to provide for territorial claims to qualifying guano islands, illustrating the strategic value governments attached to fertilizer supplies.

The nitrogen combination became part of a broader system of horizontal and vertical coordination. Horizontally, the firms pooled operations through an enlarged *Interessengemeinschaft* in dyes, a profit-sharing combination short of merger,⁴¹ and, from 1919, through the German Nitrogen Syndicate, which placed competing nitrogen producers under a common agreement. Vertically, the syndicate incorporated agricultural buyers into governance and distribution. Its board also included representatives of the Reich and organized labor, embedding the arrangement in a wider corporatist structure.⁴² The founding agreement gave buyers representation, required transparent prices, gave the state a veto over price increases, and routed distribution through farmer organizations. With a focus on scheduling negotiated prices between fertilizer producers and farmers, the arrangement came to resemble a two-part tariff.

⁴¹The Hoechst–Cassella–Kalle group and the Weiler-ter-Meer works joined the enlarged *Interessengemeinschaft* in 1916, and Griesheim-Elektron followed in 1917. The combination became the nucleus of *IG Farben* in 1925. Two decades later, *IG Farben* built and operated synthetic-fuel and rubber capacity used in German rearmament. Its directors were tried at Nuremberg in 1947–48, and the Allies subsequently broke up the firm under the broader decartelization program (Borkin, 1978; Crane, 2023).

⁴²The syndicate did not initially sell directly to farmers. Output was distributed by contract: 50 percent through the German farmers’ purchasing association, 10 percent through the agricultural trade bank (*Delhabank*), 10 percent to compound-fertilizer manufacturers, and 30 percent through the existing BASF and DAVV sales organizations.

Figure 2: Cartels, Financing, and Synthetic Nitrogen



Note. The case study uses the corporate accounts, financing records, patents, prices, and production statistics described in Appendix D.1. Panel A shows cumulative investment in the nitrogen program, in millions of constant 1913 marks, from the financing database itemized in Appendix Table D.1; 78% is coordinated cartel capital, including retained earnings. Panel B shows nitrogen-chemistry patents per year. Panel C shows the price of contained nitrogen in natural Chilean saltpeter and synthetic sulfate of ammonia, in constant 1913 U.S. dollars per kilogram. Panel D compares Chilean nitrate output with world synthetic output, in millions of tons of contained nitrogen per year. Points mark observed years; segments without points are interpolated. Dashed lines mark the 1905 cartel agreement and the 1912 Haber–Bosch breakthrough. The band marks the First World War; these years are drawn faintly and omitted from the connecting line.

3 A Model of Cartels and Investment Finance

We next distill the broader historical evidence in Sections 2.1–2.2 and the case study in Section 2.3 into a two-period framework with one upstream sector and one downstream buyer. The model traces the effects of changes in upstream conduct. Relative to competition, cartelization restricts current output and raises current profit. When external finance is scarce, retained profit can fund cost-reducing investment that the upstream sector could not otherwise undertake. If the resulting

cost reduction is sufficiently large, long-run output may rise above, and price may fall below, their competitive benchmarks. With commitment, a two-part tariff between the upstream sector and the buyer can remove the period-2 markup while preserving the period-1 funds. Market power thus trades a static loss against a potential dynamic gain. Under the conditions derived below, the surplus-maximizing degree of market power balances these forces and rises when external finance is scarcer or future surplus receives greater weight.

3.1 Setup

An upstream sector sells to a downstream buyer over two periods, $t = 1, 2$, under complete information. In period t , the buyer has quasilinear payoff $V(Q_t) + x_t$, where x_t is the numeraire. Inverse demand is therefore $P(Q) = V_Q(Q)$, with $V_Q > 0 > V_{QQ}$. Upstream costs are $C_1(Q)$ in period 1 and $C_2(Q, I)$ in period 2, with marginal cost constant or increasing in output. Investment $I \geq 0$ is chosen in period 1 at unit cost and lowers both period-2 total cost and marginal cost: $C_{2,I} < 0$ and $C_{2,QI} < 0$.

Deviations from upstream competitive conduct are indexed by $\mu \in [0, 1]$, where $\mu = 0$ denotes competition and $\mu = 1$ full collusion. We interpret cartelization as an increase in μ .⁴³ Conduct is set once and remains fixed across periods. It represents a durable commitment or control structure, rather than a choice made after investment is sunk.⁴⁴ In our setting, court enforcement of the contract sustains this commitment, not repeated-game punishment. Enforceability also matters after investment: the member whose cost falls gains most from undercutting the cartel price, and a quota backed by enforceable fines removes that incentive, so the other members can accept its expansion. Period- t output satisfies the conduct equation

$$V_Q(Q_t) + \mu V_{QQ}(Q_t) Q_t = C_{t,Q},$$

which nests competition at $\mu = 0$ and full profit internalization at $\mu = 1$. Holding investment

⁴³This does not conversely require every positive value of μ to arise from an explicit cartel agreement.

⁴⁴The commitment may be sustained by state enforcement of a private conduct agreement, up to some admissible level (Alonso and Matouschek, 2008; Amador and Bagwell, 2013), or by persistent ownership and control. Appendix C.4 provides an oligopoly foundation: N sellers that internalize a share $\kappa \in [0, 1]$ of the harm to rivals, as under fines enforceable up to that share, sustain $\mu^U(\kappa) = \frac{1}{N} + \kappa(1 - \frac{1}{N})$ when unconstrained and $\mu^C(\kappa) \leq \mu^U(\kappa)$ when borrowing-constrained. Quantity conduct itself has a capacity foundation: under capacity precommitment and price competition, outcomes are Cournot (Kreps and Scheinkman, 1983); German cartels negotiated over quotas, and the capacity race was the documented cheating margin.

fixed, greater market power contracts output and raises operating profit for $\mu < 1$.⁴⁵

3.2 Market Power, Profits, and Investment

We first show how market power affects investment when retained profit is a source of finance.

The private marginal value of investment is

$$\pi_{2,I}(\mu, I) = \underbrace{-C_{2,I}}_{\text{cost saving}} + \underbrace{[(1 - \mu)V_{QQ}Q_2]}_{\text{margin on induced output}} Q_{2,I}. \quad (1)$$

The first term is the direct cost saving. The second values the induced output at marginal revenue net of marginal cost; it is nonpositive and equals zero at $\mu = 1$.

In period 1, the upstream sector can borrow $b \geq 0$ at the gross market rate $1 + r$. Let $\delta \equiv 1/(1 + r) \in (0, 1]$ denote the corresponding market discount factor. Absent the borrowing constraint, investment is

$$I^p(\mu; r) = \arg \max_{I \geq 0} \{-I + \delta \pi_2(\mu, I)\}.$$

An interior solution satisfies $\delta \pi_{2,I} = 1$.⁴⁶

Assumption 1 (Financial constraint). *External finance is limited: the upstream sector can borrow at most B , so $b \leq B$. The borrowing part of the financial constraint caps investment at external finance plus period-1 earnings π_1 .*⁴⁷

$$I \leq B + \pi_1(\mu).$$

The investment part caps investment at the project the sector would undertake with unlimited finance, I^p . Actual investment is therefore the smaller of the two:

$$I(\mu) = \min\{I^p(\mu; r), B + \pi_1(\mu)\}. \quad (2)$$

⁴⁵Induced outputs are positive, locally unique, and differentiable, with $Q_{1,\mu} < 0$, $Q_{2,\mu} < 0$, and $Q_{2,I} > 0$, under the standard local stability condition $(1 + \mu)V_{QQ}(Q_t) + \mu V_{QQQ}(Q_t)Q_t - C_{t,QQ} < 0$. Operating profits are $\pi_1(\mu) = P(Q_1)Q_1 - C_1(Q_1)$ and $\pi_2(\mu, I) = P(Q_2)Q_2 - C_2(Q_2, I)$, with period-2 profit concave in investment, $\pi_{2,II} < 0$. The conduct equation gives the envelope conditions $\pi_{1,\mu} = (1 - \mu)V_{QQ}(Q_1)Q_1 Q_{1,\mu}$ and $\pi_{2,\mu} = (1 - \mu)V_{QQ}(Q_2)Q_2 Q_{2,\mu}$, both positive for $\mu < 1$ and zero at $\mu = 1$.

⁴⁶The loan and its repayment are transfers that cancel: the numeraire x_t nets borrowing and dividends period by period, so neither enters total surplus.

⁴⁷The upstream sector cannot issue equity. Nonnegative period-1 dividends, $D_1 = \pi_1(\mu) - I + b \geq 0$, therefore imply $I \leq \pi_1(\mu) + b$. Because $\delta(1 + r) = 1$, the loan and its repayment cancel in present value. Borrowing only relaxes the period-1 constraint, so the sector borrows up to B and invests subject to $I \leq B + \pi_1(\mu)$.

The sector is borrowing-constrained when the borrowing part binds, $I = B + \pi_1$, and unconstrained when only the investment part binds, $I = I^p$. The unconstrained regime includes the possibility of no investment, $I^p = 0$.⁴⁸

Assumption 2 (Binding borrowing constraint). *The financeable bound in (2) binds for every $\mu \in [0, 1]$:*

$$I(\mu) = B + \pi_1(\mu) \leq I^p(\mu; r).$$

Equivalently, $\delta\pi_{2,I}(\mu, I(\mu)) \geq 1$, so the upstream sector would invest more if additional finance were available. It follows that $I_\mu = \pi_{1,\mu} \geq 0$, with equality at $\mu = 1$, and $I_B = 1$.

The baseline analysis maintains a binding borrowing constraint. Investment has a high private return, but external finance is limited, so each marginal unit of retained earnings is invested.⁴⁹

Along the borrowing-constrained path, greater market power raises earnings and the investment financed by those earnings. The additional investment lowers period-2 marginal cost and raises period-2 profit.⁵⁰

Proposition 1 (Output and prices under market power). *At an interior, borrowing-constrained conduct level $\mu \in (0, 1)$, market power contracts period-1 output and raises period-1 price:*

$$Q_1(\mu) < Q_1(0), \quad P(Q_1(\mu)) > P(Q_1(0)).$$

In period 2, the direct effect of market power and the effect of the investment it finances work in opposite directions:

$$\frac{dQ_2}{d\mu} = \underbrace{Q_{2,\mu}}_{<0} + \underbrace{Q_{2,I} \pi_{1,\mu}}_{>0}.$$

Suppose period-2 marginal profit under conduct μ is strictly decreasing in Q . If the investment-induced

⁴⁸ $I^p = 0$ when the upstream sector appropriates no return to investment under competition, $\pi_{2,I}(0, \cdot) = 0$. One example is constant marginal cost with no fixed cost, where price equals marginal cost. Appendix C.5 develops this case.

⁴⁹This regime can arise when the upstream sector also sells in a price-taking outside market that adds $A\phi(I)$ to period-2 profit, where $A \geq 0$, $\phi_I > 0$, and $\phi_{II} \leq 0$. At $I = B + \pi_1(\mu)$, the borrowing constraint binds whenever $\delta[\pi_{2,I}(\mu, I) + A\phi_I(I)] \geq 1$. The left-hand side increases in A , so a larger outside market makes a binding borrowing constraint more likely.

⁵⁰These comparative statics hold throughout the borrowing-constrained regime. Operating profit rises with market power, $\pi_{1,\mu} > 0$ for $\mu < 1$, by the envelope condition. Investment rises one for one with retained profit, $I_\mu = \pi_{1,\mu}$, by Assumption 2. Because $C_{2,QI} < 0$ and $I_\mu > 0$, period-2 marginal cost falls. Period-2 profit also rises: $d\pi_2/d\mu = \pi_{2,\mu} + \pi_{2,I}I_\mu > 0$ for $\mu < 1$, since $\pi_{2,\mu} \geq 0$ by the envelope condition and $\pi_{2,I} > 0$ under Assumption 2.

reduction in marginal cost at $Q_2(0, I(0))$ exceeds the market-power wedge at that output, then period-2 output exceeds its competitive benchmark:

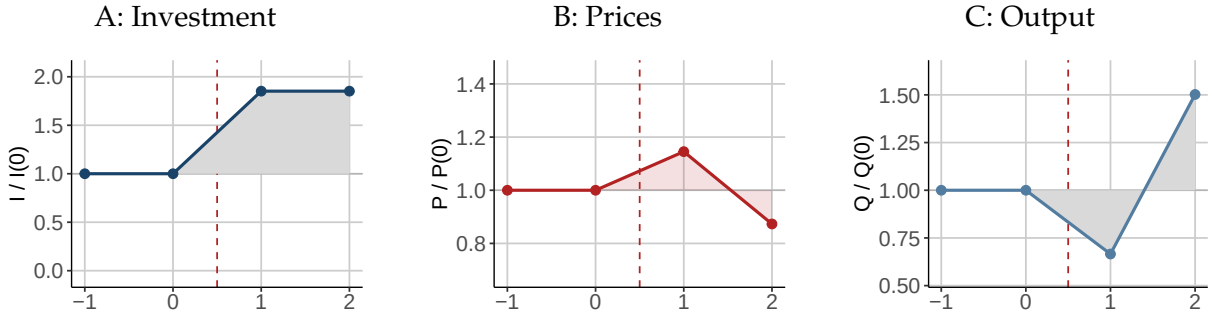
$$Q_2(\mu, I(\mu)) > Q_2(0, I(0)).$$

Under the same condition, period-2 price falls below its competitive benchmark:

$$P(Q_2(\mu, I(\mu))) < P(Q_2(0, I(0))).$$

The period-1 effect is the familiar static contraction. In period 2, the investment response works against this contraction. When the cost reduction is sufficiently large, output may exceed, and price may fall below, the corresponding competitive benchmarks. Figure 3 illustrates this case across the pre-cartel, short-run, and long-run periods.

Figure 3: Investment, Prices, and Output across Periods



Note. Investment, prices, and output across periods in a borrowing-constrained sector with N sellers (Appendix C.4), as enforceability κ rises from 0 to 0.49. Each series is relative to the same sector at $\kappa = 0$, the no-contract benchmark, shown as period 0. The dashed vertical line marks cartel formation. Period 1 is the short run and period 2 the long run. In period 1, the cartel contracts output and raises price. Investment is chosen in period 1 and becomes productive in period 2, when it lowers marginal cost. For the parameters shown, the cost reduction is large enough that period-2 output rises above, and price falls below, the benchmark. Period -1 repeats the benchmark for visual reference and has no separate model interpretation. Parameters are in Appendix Table C.1.

Remark 1 (Two channels: financing and appropriability). When the borrowing constraint binds, the upstream sector invests up to the financeable bound. By raising period-1 earnings, market power supplies the *funds* for additional investment. A distinct appropriability channel can operate when the sector is unconstrained but the upstream sector captures no return to investment at $\mu = 0$. For example, with constant marginal cost and no fixed cost, $I^p(0) = 0$; market power may then supply the *incentive* to invest. Appendix C.5 formalizes this channel.

The baseline analysis focuses on financing. Appendix Figure A.3 isolates this mechanism: it repeats Figure 3 for an otherwise identical unconstrained sector, whose investment does not respond. Without the investment response, the period-2 recovery disappears.

3.3 Efficient Contracting

The baseline assumes linear pricing in both periods. Under market power, the period-2 markup restricts trade after investment is sunk. We now allow the upstream sector and the buyer to use a two-part tariff. The tariff can restore efficient period-2 trade without changing the period-1 profits that financed investment. For a given I , the efficient quantity $Q^E(I)$ satisfies

$$V_Q(Q^E(I)) = C_{2,Q}(Q^E(I), I).$$

Proposition 2 (Efficient vertical terms). *Fix a conduct level μ and maintain the binding borrowing constraint (Assumption 2). Suppose the parties can commit to an enforceable two-part tariff for period-2 trade, $\mathcal{T}(Q) = wQ + T$. Setting*

$$w = C_{2,Q}(Q^E(I(\mu)), I(\mu))$$

implements the efficient period-2 quantity $Q^E(I(\mu))$ and removes the period-2 markup. Because T is a lump-sum transfer, it can divide the resulting surplus so that both parties are at least as well off as under linear pricing. Period-1 output and profit are unchanged. Finance therefore remains binding, and investment remains $I(\mu) = B + \pi_1(\mu)$.

The two parts of the tariff separate the two roles of cartel rents. The marginal price w sets the price of additional units at marginal cost, removing the markup on period-2 trade. The fixed part T transfers surplus without distorting quantities, so the profits that finance investment are preserved. Empirically, rebates or discounts granted only on purchases beyond a threshold implement the same margin structure: buyers pay the posted price on inframarginal units and the rebated price on additional units (Section 2.2). The tariff weakly raises joint surplus relative to linear pricing, but it requires commitment.⁵¹

⁵¹At the efficient marginal price $w = C_{2,Q}(Q^E(I), I)$, the upstream sector earns no margin on the marginal unit and, under constant marginal cost, no margin on any unit. Without commitment, it would therefore raise the price ex post. Anticipating this deviation, the parties would revert to linear pricing.

3.4 Surplus

We next describe how market power affects total surplus. At a fixed conduct level, differentiating period-2 surplus, $V(Q_2) - C_2(Q_2, I)$, with respect to investment gives its marginal social value:

$$S(\mu, I) \equiv \underbrace{-C_{2,I}}_{\text{cost saving}} + \underbrace{[-\mu V_{QQ} Q_2]}_{\text{value of output expansion}} Q_{2,I} . \quad (3)$$

Proposition 3 (Investment wedge). *The private and social marginal values of investment differ by the downstream surplus generated by the investment-induced output:*

$$S(\mu, I) - \pi_{2,I}(\mu, I) = -V_{QQ}(Q_2) Q_2 Q_{2,I} = (P_2 - \text{MR}_2) Q_{2,I} > 0, \quad (4)$$

for any demand with $V_{QQ} < 0$, where $P_2 = V_Q(Q_2)$ is price and $\text{MR}_2 = V_Q(Q_2) + V_{QQ}(Q_2) Q_2$ is marginal revenue. The upstream sector internalizes the cost saving $-C_{2,I}$ in full but values the investment-induced output at marginal revenue rather than price.⁵²

The wedge in Proposition 3 is one downstream distortion: the upstream sector does not capture the full social value of the output created by investment. The markup is another, because it restricts downstream production. Total surplus accounts for both margins.

Let $\beta \in (0, 1]$ denote the social discount factor. Writing the dependence of output on conduct and investment explicitly, total surplus is

$$W(\mu) = V(Q_1(\mu)) - C_1(Q_1(\mu)) - I(\mu) + \beta [V(Q_2(\mu, I(\mu))) - C_2(Q_2(\mu, I(\mu)), I(\mu))]. \quad (5)$$

Proposition 4 (Marginal effect on surplus). *The marginal effect of market power on total surplus can be written as a dynamic gain minus a static loss:*

$$W_\mu(\mu) = G(\mu) - L(\mu), \quad G \equiv [-1 + \beta S(\mu, I(\mu))] I_\mu, \quad L \equiv L_1 + \beta L_2, \quad (6)$$

where $L_t \equiv [-\mu V_{QQ}(Q_t) Q_t] (-Q_{t,\mu}) \geq 0$ is the period- t markup multiplied by the output withheld. Both L_1 and L_2 vanish under competition, so $L(0) = 0$.

⁵²Whether the upstream sector underinvests or overinvests in levels is a separate question. If the market discount factor exceeds the social discount factor, it may overinvest even though $\pi_{2,I} < S$ pointwise.

The dynamic term G is the net social value of the investment financed by market power: the discounted marginal return βS less the unit cost of investment, multiplied by the extent to which market power relaxes the borrowing constraint, I_μ . For $I_\mu > 0$, this term is positive if and only if $\beta S > 1$.

Proposition 5 (Marginal surplus at competition). *Under Assumption 2, $L(0) = 0$. At $\mu = 0$, the markup is zero, so the output-expansion component of $S(0, I(0))$ vanishes and $S(0, I(0))$ reflects the cost saving alone. Total surplus rises with market power at the competitive benchmark, $W_\mu(0) > 0$, if and only if the discounted gross social return to the marginal investment financed by market power exceeds its unit cost:*

$$\beta S(0, I(0)) > 1. \quad (7)$$

This result depends on the financing channel. Under the appropriability channel in Remark 1, marginal surplus at competition is zero, $W_\mu(0) = 0$, but market power can still raise total surplus if it creates a discrete incentive to invest. Appendix C.5 develops that case.

We finally return to vertical contracting. Define the period-2 surplus recovered by efficient trade as

$$\Delta(\mu, I) \equiv [V(Q^E(I)) - C_2(Q^E(I), I)] - [V(Q_2(\mu, I)) - C_2(Q_2(\mu, I), I)].$$

Because $Q^E(I)$ maximizes period-2 total surplus for a given I , $\Delta(\mu, I) \geq 0$, with equality when the allocation under linear pricing is already efficient.

Corollary 1 (Efficient contracting recovers the period-2 loss). *Under the two-part tariff of Proposition 2, total surplus is*

$$W^E(\mu) = W(\mu) + \beta \Delta(\mu, I(\mu)) \geq W(\mu).$$

Given investment, period-2 trade is undistorted. Let

$$S^E(I) \equiv -C_{2,I}(Q^E(I), I),$$

denote the marginal social value of investment under efficient period-2 trade. Then

$$W_\mu^E(\mu) = [-1 + \beta S^E(I(\mu))] I_\mu - L_1(\mu).$$

Only the period-1 static loss remains.

3.5 Optimal Market Power

The preceding results describe how market power moves total surplus; we now characterize the degree of market power that maximizes it, $\mu^W \in \arg \max_{\mu \in [0,1]} W(\mu)$. Under condition (7), competition is not a local optimum: by Proposition 5, a marginal increase in market power raises total surplus at $\mu = 0$.

Corollary 2 (Suboptimality of full profit internalization). *Under Assumption 2, market power no longer relaxes the borrowing constraint at $\mu = 1$: the envelope condition gives $I_\mu(1) = \pi_{1,\mu}(1) = 0$. Thus $G(1) = 0$ while $L(1) > 0$, so*

$$W_\mu(1) = -L(1) < 0.$$

It follows that $\mu^W \neq 1$: at the margin, full profit internalization generates no additional investment but continues to impose a static loss.

Corollary 3 (Interior optimum). *Suppose W_μ is continuous and strictly decreasing on $(0,1)$.⁵³ If $W_\mu(0) > 0$ (Proposition 5) and $W_\mu(1) < 0$ (Corollary 2), then there is a unique interior maximizer $\mu^W \in (0,1)$. At this point, the dynamic gain equals the static loss:*

$$G(\mu^W) = L(\mu^W).$$

We next consider how the surplus-maximizing conduct level varies with external finance B and the social discount factor β .

Proposition 6 (Comparative statics of optimal market power). *At an interior, borrowing-constrained optimum μ^W with $W_{\mu\mu}(\mu^W) < 0$, the sign of $d\mu^W/dx$ is the sign of $W_{\mu x}(\mu^W)$.⁵⁴ A higher social discount factor raises optimal market power. If investment has diminishing returns, $S_I \leq 0$ and $L_{2,I} \geq 0$, with at*

⁵³Strict monotonicity is an additional regularity condition on demand and cost curvature, as is $W_{\mu\mu}(\mu^W) < 0$ in Proposition 6.

⁵⁴The market interest rate does not affect optimal conduct in the constrained regime: $I_r = I_{\mu r} = 0$, so $d\mu^W/dr = 0$. The upstream sector already invests up to the financeable bound.

least one inequality strict, scarcer external finance also raises optimal market power:

$$\frac{d\mu^W}{d\beta} > 0, \quad \frac{d\mu^W}{dB} < 0. \quad (8)$$

The model also has a policy interpretation that we do not test directly. Enforcing cartel agreements can transfer rents to financially constrained producers without an explicit budgetary outlay, but it does so by imposing a static distortion. This creates a conditional policy trade-off between current distortions and investment financed by internal rents.

3.6 Predictions

We derive three sets of empirical predictions, moving from cartel members to downstream firms and then to districts and markets. In the model, cartel membership corresponds to higher conduct μ . Enforceability κ sustains conduct up to $\mu^U(\kappa)$ in an unconstrained sector and up to $\mu^C(\kappa) \leq \mu^U(\kappa)$ in a borrowing-constrained sector (Appendix C.4).

Prediction 1.1 (Cartel Members). Market power raises current earnings. When the borrowing constraint binds, these internal funds relax it: $I_\mu = \pi_{1,\mu}$. The additional investment lowers period-2 marginal cost and raises period-2 profit. Under the condition in Proposition 1, the cost reduction can more than offset the direct contractionary effect of market power, so period-2 output may rise relative to its competitive benchmark.

We follow this chain from earnings to investment, upgrading, and scale. Earnings are measured by revenue; investment by reserves, capital, and capital expenditure; upgrading by patenting and exporting; and scale by production and employment. If the financing channel operates as in the model, higher earnings should go to investment rather than to dividends.

Prediction 1.2 (Borrowing Constraints). These effects arise only where the borrowing constraint binds. In an unconstrained sector, the investment part of the financial constraint binds, rents are not invested, and a cartel only restricts output. The financing mechanism therefore predicts larger effects where internal funds are most valuable. We use capital intensity as a proxy for settings in which required outlays are large relative to available finance. On this interpretation, the association between cartel membership and development should be stronger in capital-intensive industries.

The same logic motivates us to examine whether membership is accompanied by denser interlocking directorates and bank connections, which may facilitate the financing and governance of investment.

Prediction 2.1 (Downstream Burden). An upstream markup raises the input costs of downstream firms and reduces their output in period 1. In period 2, cartel-financed investment lowers the upstream price relative to a counterfactual without that investment. If the cost reduction is sufficiently large, the price may fall below its competitive benchmark (Proposition 1).

Prediction 2.2 (Vertical Contracts). A two-part tariff between the cartel and its buyers removes the period-2 markup and increases the scope for such a reversal (Proposition 2).

Empirically, we distinguish input links that a cross-sector agreement governed from those it did not, using the state-mediated adversarial hearings around which such agreements between cartels and their buyers became common (Section 2.2). Through ungoverned links, exposure to cartelized inputs should be associated with lower downstream output and employment. Through governed links, the association should weaken and may turn positive if cost reductions and vertical contracting are sufficiently strong.

Prediction 3 (Selection and Aggregate Effects). Enforceability raises surplus only where the borrowing constraint binds and the investment it finances is worth its cost (Proposition 5), so aggregate gains depend on which sectors cartelize. We ask whether gains to existing firms appear in local industrial activity and market structure. Higher earnings and, when the borrowing constraint binds, greater investment may support incumbent expansion and survival while strengthening incumbents relative to potential entrants. We therefore examine whether districts with greater cartel presence have higher industrial employment and whether markets with greater cartel presence have lower entry, higher incumbent survival, and greater concentration.

The following empirical analysis traces these three margins. We begin with cartel members (Section 5), examine the associations with downstream firms (Section 6.1), and then study district employment and market structure (Section 6.2).

4 Data and Empirical Strategy

4.1 Data

Units. Our data originate in the digitization and linkage of a large collection of primary sources. Appendix D describes each source and construction procedure in detail. Below, we summarize the main components. The analysis relies on four units: firms, years, industries, and geographies. A firm (i) is a German joint-stock company, and a year (t) is a calendar year between 1882 and 1933. We assign each firm to four-digit NACE codes and to the municipality of its headquarters.⁵⁵ For the analysis, we aggregate firms into a primary NACE three-digit category (industry s), and into district geographic units (geography d). A market is the intersection of an industry and a geography (Wolf, 2009). We complement these units with a large set of geographic and industry-level covariates (Appendix D.2).

Firm panel. We construct the firm panel from two investor manuals, *Saling's Börsen-Jahrbuch* (Hertslet et al., 1882–1933) and the *Handbuch der deutschen Aktiengesellschaften* (Thieme, 1897–1933). Together, they provide annual coverage of listed and unlisted joint-stock firms. We digitize each firm entry and extract structured information on operations, balance sheets, income statements, directors, and supervisory-board members. The resulting unbalanced panel contains 27,109 firms and 372,584 firm-years. Coverage differs across outcomes: only select volumes reported physical output and employment, and not every volume reported dividends, so the samples below vary by outcome and each estimate uses the firm-years for which its outcome is observed.

Cartel membership. We classify firm i as a cartel member in year t if it belonged to at least one cartel that year. We compile cartel names from the *Kartell-Rundschau*, a trade journal reporting formations, dissolutions, and membership changes (Tschierschky and Borger, 1903–29), supplemented by three cross-sectional surveys (Reichsministerium des Innern, 1906; Silberberg, 1910; Wagenführ, 1931). We then match these names to the operations abstracts in the investor manu-

⁵⁵We begin the panel in 1882 because it is the year of the first empire-wide industrial census in Imperial Germany. The census allows us to assess how representative joint-stock companies were of the broader regional industrial composition (Appendix D.10). Consistent with recent research using similar sources (De Loecker et al., 2020), our sample closely tracks broader industrial trends, although it is not fully representative in levels. We map each of the 75,311 municipalities to one of the 928 Imperial German counties as of 1882. Counties nest within 89 districts and 26 states; Appendix Figure D.2 maps these four geographic levels.

als.⁵⁶ This procedure links 5,797 firms to 3,806 distinct cartels. For each cartel we also record, from the same sources, its founding year and how its contract bound the members: by price agreements, production quotas, or sale through a common sales syndicate.

Court decisions. To measure changes in cartel enforceability, we digitize reported decisions from the two courts governing cartel law: 5,688 decisions of the Imperial Court through 1923 (Reichsgericht, 1882–1933) and 172 decisions of the Cartel Court thereafter (Reichsverband der Deutschen Industrie, 1924–33). For each decision we record the parties with their industries and locations, the question decided, and the ruling.

Firm performance outcomes. Our main firm outcomes follow the chain from earnings to investment, upgrading, and scale. We measure upgrading by patenting and exporting, scale by production and employment, and investment in part by capital. *Upgrading.* We measure upgrading toward the technological and export frontier through (i) an indicator of whether the firm was granted at least one patent in the year, matched by firm name to the *Reichspatentblatt* (Reichspatentamt, 1918–33), and (ii) an indicator of whether the operations abstract of the firm reports export activity. *Scale and capital.* We measure the scale of production through (iii) physical output and (iv) employment, and investment through (v) capital. Output requires the most construction because firms report quantities in heterogeneous units. We convert compatible units to a common base and use each firm’s most consistently observed physical quantity. Employment is the reported total headcount when available and otherwise the sum of workers, salaried employees, and officials. Capital is year-end share capital, a stock, in constant 1913 marks.⁵⁷

Financing outcomes. The financing mechanism motivates four further outcomes. Earnings are measured by revenue, a flow. Investment is measured, beyond capital, by balance-sheet reserves, which proxy for accumulated retained funds, and by capital expenditure. The dividend rate is the declared dividend in percent of share capital. All monetary amounts are in constant 1913 marks.

⁵⁶Because cartel membership could affect firm prospects, the handbooks reported cartel affiliations. Wartime U.S. intelligence relied on the same feature, noting that the *Handbuch* carried “a statement concerning the principal price and market-regulating associations to which a corporation belonged” (OSS, 1944, p. vi).

⁵⁷Output and employment are reported for fewer firm-years than the other outcomes. We conduct robustness checks across a range of interpolation choices, such as using only directly observed values or varying the treatment of isolated gaps, in Appendix E.4.

Organizational outcomes. For each firm-year, we count interlocking directors, who also sit on another firm’s board, and directors affiliated with a bank, the state, or science or engineering. Affiliations are identified from the offices and titles reported in board rosters.

Input–output linkages. To measure spillovers to firms outside cartels, we use Germany’s 1936 input–output table (Fremdling and Staeglin, 2014), the earliest available. Combining its input weights with time-varying industry cartel shares yields each firm’s exposure to cartelized inputs.⁵⁸

Industrial censuses. We construct a county–industry employment panel from the five industrial censuses of 1882, 1895, 1907, 1925, and 1933.

War-economy records. From declassified records covering military procurement, secret war patents, and wartime production boards, we construct three firm-level indicators of involvement in the war economy of 1914–1918: whether the firm held a military procurement contract, whether it held a secret war patent, and whether one of its directors sat on a war board.

4.2 Empirical Strategy

Our first design aims to compare firms entering cartels with otherwise similar firms before and after cartel formation. As described in Section 2.2, the setting provides substantial variation in cartels across products and regions and over time, reflecting historical economic and legal fragmentation. Cartel organization therefore differed substantially across products and regions, while discrete changes in enforceability generated uneven shifts over time. This variation is visible in our data. Cartel formation occurred in distinct waves rather than evolving smoothly, with pronounced increases around major shifts in legal enforceability (Figure 1). Membership also varied substantially across geography (Figure 4, Panel A).

We begin by using this variation across the full sample of firms. For firm i in year t ,

$$y_{it} = \beta D_{it} + \alpha_i + \delta_t + \varepsilon_{it}, \quad (9)$$

⁵⁸This construction assumes that broad input-use patterns were sufficiently stable for the 1936 table to proxy earlier production linkages. We therefore interpret the exposure measure as approximate. The results remain similar when we exclude sectors whose input structure changed substantially over the sample period (Appendix E.4).

where y_{it} is a firm outcome, D_{it} indicates cartel membership in year t , α_i denotes firm fixed effects, and δ_t year fixed effects. Firm fixed effects absorb time-invariant differences across firms, while year fixed effects absorb shocks common to all firms in a year. Thus, β captures the within-firm association between cartel membership and the outcome relative to firms not in cartels in the same year. Indicator outcomes enter in levels, so β can be interpreted as a change in probability; continuous outcomes enter in logarithms, and counts as the logarithm of one plus the count, so β can be interpreted as an approximate percent change; the dividend rate enters in percent of share capital, so β is a change in percentage points. We cluster standard errors by firm.

Consistent with cartel entry depending in part on this fragmented environment, observable differences between eventual members and firms that never entered a cartel were modest. Figure 4, Panel B, relates future membership to predetermined firm, geographic, and industry characteristics measured in the first observed year for each firm, controlling for year and listing status. No estimated association exceeds 0.06 per standard deviation; firm size is the strongest, but still limited, predictor.

This comparison describes differences in predetermined characteristics. A corresponding dynamic question is whether entering and comparison firms were already on different outcome trajectories before cartel entry. We examine this using an event-study specification,

$$y_{it} = \sum_{k \neq -1} \beta_k \mathbb{1}\{t - e_i = k\} + \alpha_i + \delta_t + \varepsilon_{it}, \quad (10)$$

where e_i is the year firm i first enters a cartel and k indexes years relative to entry, with $k = -1$ omitted.⁵⁹ Coefficients for $k < 0$ trace differences before entry, while those for $k \geq 0$ trace subsequent dynamics. We estimate the event-study coefficients with the imputation estimator of Borusyak et al. (2024), which is robust to treatment-effect heterogeneity under staggered entry.

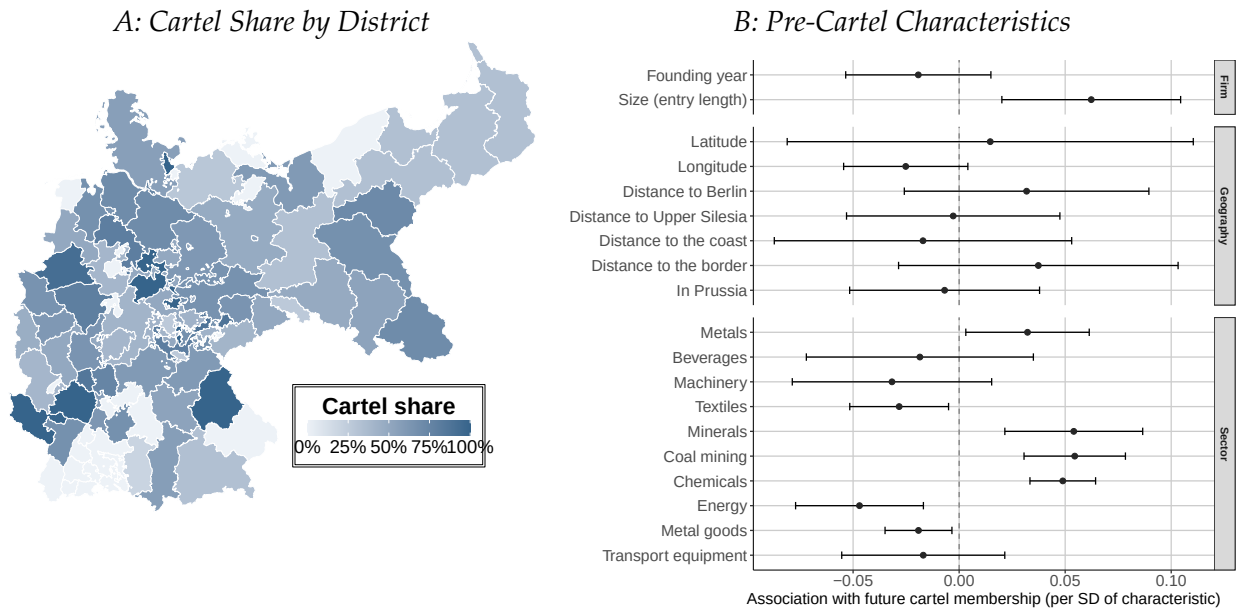
The design assumes that, had they stayed out, members would have tracked nonmembers, and that firms did not anticipate their entry. Predetermined characteristics and pre-entry trends help assess whether cartel entry was predictable from observable differences or prior outcome dynamics. They do not, however, establish that subsequent changes were caused by member-

⁵⁹The event study treats first cartel entry as absorbing. Because cartel membership was highly persistent, this convention closely tracks contemporaneous membership; Appendix E.4 shows that the results are similar under alternative estimators and treatment definitions.

ship. Cartel formation could still coincide with shocks that differentially affected entering firms, and membership could affect firms used as comparisons. Appendix E therefore organizes the robustness analysis around four concerns. First, we examine selection into cartels by flexibly controlling for predictors of formation and by matching and reweighting on pre-cartel characteristics (Appendix E.1). Second, we address coincident industry, geographic, and market shocks using industry-by-year, district-by-year, and market-by-year fixed effects and by excluding strategically exposed sectors (Appendix E.2). Third, we assess spillovers to the comparison group by varying market and treatment definitions and excluding nonmembers in cartelized markets (Appendix E.3).⁶⁰ Finally, we report robustness across choices of estimator, sample, measurement, and clustering using heterogeneity-robust estimators, subsample and leave-one-out exercises, alternative variable definitions, and alternative clustering schemes (Appendix E.4). Appendix Table A.1 provides summary statistics for every variable used in the analysis.

⁶⁰Cartel membership was highly persistent: about 67% of entrants remained documented members a decade after entry (Appendix Figure A.4, Panel A). Cartelized markets were also often nearly complete: 16% contained no nonmember, while the median nonmember share was 50% (Panel B). This is consistent with contemporary accounts of outsiders being exceptional in many industries.

Figure 4: Cartel Descriptives



Note. Panel A: share of listed industrial firms ever in a cartel within the sample window, by 1882 district (the government region, else province or state; industries pooled); districts with fewer than three firms are grayed. Panel B: coefficients with 95% confidence intervals from one joint linear-probability regression of future cartel membership on predetermined characteristics, over all firms, taken at each firm's first observed year, with year and listing-status fixed effects and standard errors clustered by decade. The characteristics are firm founding year and size; county-centroid geography (latitude and longitude, and distances to Berlin, the Ruhr, Upper Silesia, the coast, and the national border, with a Prussia indicator); and indicators for the largest industries. Size and the distances enter as the logarithm of one plus the value, and founding year and the coordinates in levels; all characteristics are standardized, so each coefficient is the partial association per standard deviation with a firm ever entering a cartel, holding the others fixed. Sample 1882–1933.

4.3 Enforceability Instrument

The within-firm design uses all the variation in cartel membership, whatever its source. Our second design uses only the variation in membership predicted by differential exposure to a change in legal enforceability. The change is the 1897 ruling of the Imperial Court described in Section 2.2. In a dispute among Saxon wood-pulp producers, the court upheld a cartel contract and the contractual penalty by which it bound its members, and the decision anchored a line of affirming cartel rulings over the following decade. The design compares firms in the same sector whose law regions were more and less exposed to the pro-cartel rulings that followed, and uses that difference as an instrument for cartel membership.

Exposure. German private law varied by law region before the 1900 civil code, and each senate of the Imperial Court heard appeals from a fixed set of law regions. A pro-cartel ruling in a sector therefore applied more directly to firms of that sector whose law region the deciding senate heard.

For each of the 48 law regions and each senate, we measure the share of the cartel cases of the senate that arose in the region.

Instrument and estimation. The instrument for firm i in year t accumulates the pro-cartel decisions of the Imperial Court through 1914 in the sector of firm i , beginning with the 1897 ruling that upheld a cartel contract and its contractual penalty, each weighted by the share of the cartel cases of the deciding senate that arose in the law region of firm i :

$$Z_{it} = \log \left(1 + \sum_k \mathbb{1}\{t_k \leq t\} \mathbb{1}\{j(k) = j(i)\} \text{Share}_{s(k), r(i)} \right),$$

where ruling k is dated t_k , concerns sector $j(k)$, and was decided by senate $s(k)$, and $r(i)$ is the law region of firm i . The endogenous variable is cartel membership D_{it} , here an indicator equal to one from the first documented year of cartel membership of the firm onward. We use this definition because the ruling lowered the cost of forming and keeping a cartel rather than the cost of any single year of cartel membership. We estimate equation (9) by two-stage least squares with firm and year fixed effects, instrumenting D_{it} with Z_{it} . Standard errors are clustered by two-digit industry. Because the firm fixed effects absorb the level of each firm, the effect of the ruling is identified from firms observed both before and after 1897.

Relevance. The first stage requires that cartel membership rose more where pro-cartel rulings accumulated in the sector and law region of a firm. The first-stage F -statistic is 28.1 for exporting and patenting and exceeds the conventional threshold of ten in every column of the shift-share panel of Table 2. This reflects the timing encountered in the aggregate series of Figure 1: the first wave of cartel formation followed the landmark ruling.

Exclusion. The exclusion assumption is that, had the rulings not accumulated in their sector and law, affected firms would have evolved like same-sector firms elsewhere: the rulings act on outcomes only through cartel membership. Identification draws on both components of the instrument. The shares, which law regions a senate heard, were fixed by the organization of the court rather than by the outcomes of firms; the shifts, the order in which sectors' cases reached the court and under which law, must be unrelated to the outcome trends of those sectors except

through enforceability (Goldsmith-Pinkham et al., 2020; Borusyak et al., 2022). The assumption is strong: other regional characteristics, correlated with exposure, may have changed the path of firm outcomes around 1897.

We address this concern in three ways (Table 2). First, we restrict the sample to districts split by a law border and add district-by-year fixed effects, so that firms facing the same local shocks differ only in the law that applied to them. Second, we recenter the instrument on the same object built from the non-cartel business rulings of the court. Third, we keep only the rulings that overturned the lower court, the component of the rulings least anticipated by the parties.

5 Firm-Level Effects

5.1 Upgrading and Scale

Prediction 1.1 suggests that cartel membership may be associated with upgrading toward the technological and export frontier and with an expansion of scale. We begin with the within-firm design introduced in Section 4.2. Table 1 reports estimates for five firm outcomes: exporting and patenting (columns 1 and 2), and output, employment, and capital (columns 3 to 5). Each column uses the firm-years for which its outcome is observed. Exporting and patenting are observed for 281,296 firm-years of 26,023 firms, capital for nearly as many, and output and employment for fewer because the handbooks report physical quantities and headcounts only for a subset of firms.⁶¹

Upgrading. In its years of cartel membership, a firm is more likely to export and more likely to patent than in its years outside a cartel, relative to firms outside cartels in the same year. The probability of exporting is 0.06 higher (column 1), against a baseline mean of 0.07. The probability of being granted a patent is 0.02 higher (column 2), against a baseline mean of 0.05, or about 47 percent of the mean. Both coefficients are significant at the 1% level.

Scale. In years of cartel membership, output is about 13 percent higher (column 3), employment about 8 percent higher (column 4), and capital about 31 percent higher (column 5). All three coefficients are significant at the 1% level. The three outcomes move together. This is consistent with

⁶¹Output is reported in firm-specific physical units, so its level mean is not comparable across firms. We interpret the coefficients on output and employment as approximate percentage changes (Section 4.2).

an expansion of production rather than a change in factor proportions.

Dynamics. Figure 5 reports results from estimating the event study of equation (10) for the same five outcomes, in 5-year bins from 20 years before to 25 years after the first year of cartel membership. Before cartel entry, the coefficients are close to zero for every outcome. The joint tests of the pre-period leads in Appendix E.1.3 do not reject parallel trends. After entry, the coefficients rise over the first bins and stay high to the end of the window. This timing is consistent with outcomes changing after cartel entry rather than with a persistent differential trend already visible beforehand.

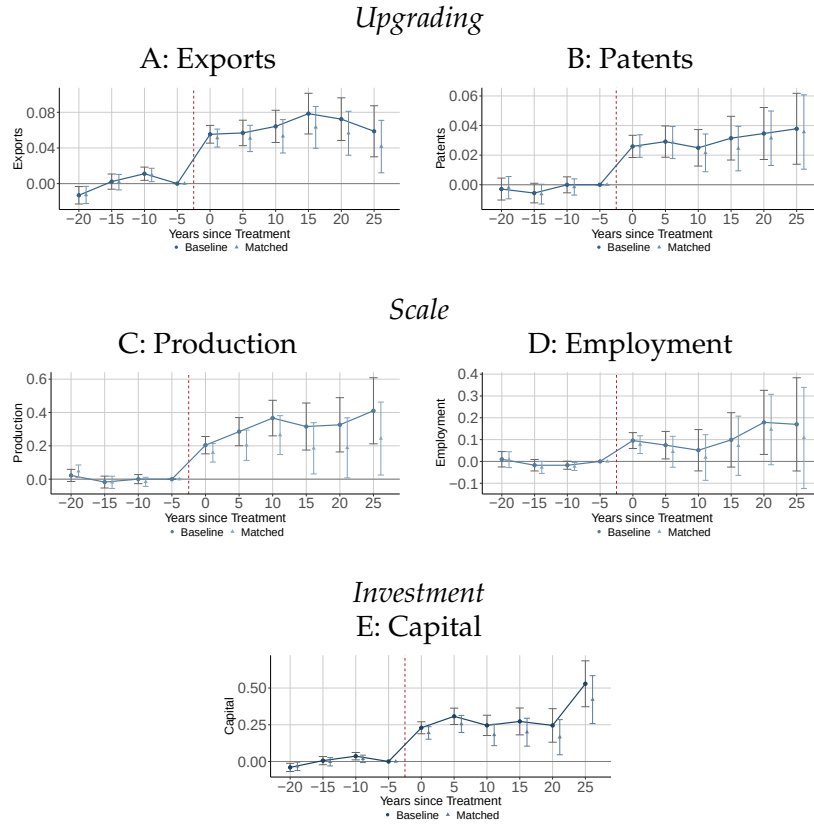
Across all five outcomes, cartel membership is associated with higher measures of upgrading and scale. We next ask whether variation generated by a change in legal enforceability yields the same qualitative pattern.

Table 1: Cartel Membership and Firm Development

	Earnings	Investment		Upgrading		Scale	
	Revenue	Reserves	Capital	Exports	Patents	Production	Employment
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Cartel Member	0.04	0.18***	0.27***	0.06***	0.02***	0.12***	0.08***
	(0.03)	(0.03)	(0.02)	(0.01)	(0.00)	(0.03)	(0.02)
R ²	0.94	0.82	0.86	0.60	0.49	0.99	0.94
Observations	38,740	172,979	201,192	281,296	281,296	55,346	41,778
Firms	6,454	16,041	21,985	26,023	26,023	4,138	3,902
Years	51	51	51	52	52	52	52
Outcome def.	(log)	(log)	(log)	(0/1)	(0/1)	(log)	(log)
Outcome mean	13.95	11.16	13.43	0.07	0.05	15.49	6.41
Standard errors	Firm	Firm	Firm	Firm	Firm	Firm	Firm
Sample	Statement	Statement	Capital	Full	Full	Operations	Operations
Firm fixed effects	✓	✓	✓	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓	✓	✓	✓

Note. Table presents results of estimating equation (9). Outcomes are exporting, patenting, output, employment, and capital, as introduced in Section 4. Each column is estimated on the firm-years for which its outcome is observed (the Sample row). Observations are at the firm-year level; the numbers of firm-years, firms, and years are shown in the table. The Outcome def. row gives the scale of each outcome: (0/1) an indicator, (log) the logarithm, (log 1+x) the logarithm of one plus the count, (%) a percentage. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

Figure 5: Cartel Membership and Firm Development: Event Study



Note. Figure presents results of estimating equation (10), with 95% confidence intervals, in 5-year bins of years relative to the first year of cartel membership; the bin before it is the reference. Upgrading: exporting (A), patenting (B); scale: production (C), employment (D); investment: capital (E), as introduced in Section 4. Standard errors are clustered at the firm level.

5.2 Instrumental-Variable Estimates

Table 2 reports two-stage least squares estimates for the same outcomes. The endogenous variable is the absorbing post-entry indicator defined in Section 4.3; the instrument is the shift-share of court rulings defined there. Panel A reports OLS on the same sample, Panel B the shift-share instrument, Panel C the instrument within districts split by a law border, and Panels D and E the recentered instruments. In Panel B, the probability of exporting is 0.36 higher under instrumented post-entry status, against a mean of 0.07, and the probability of patenting is 0.24 higher, against a mean of 0.05. Both are statistically significant. The estimates for revenue, reserves and capital, exports and patents, and production and employment are positive and significant in Panel B, with first-stage F statistics above conventional thresholds. Recentering on the non-cartel business rulings leaves the estimates nearly unchanged (Panel D).

The instrumented estimates are larger than the within-firm estimates. This gap may reflect

treatment-effect heterogeneity among firms whose cartelization responded to the ruling, differences in identifying variation, or measurement error in recorded membership. The designs do not distinguish among these explanations. We therefore emphasize their agreement in sign and report their magnitudes separately rather than treating either set as uniformly conservative.

Table 2: Cartel Membership and Firm Development: Instrumental-Variable Estimates

	Earnings	Investment		Upgrading		Scale	
	Revenue	Reserves	Capital	Exports	Patents	Production	Employment
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
<i>Panel A: OLS</i>							
Cartel member	0.05 (0.07)	0.06 (0.06)	0.20*** (0.04)	0.05*** (0.01)	0.02*** (0.01)	0.14*** (0.05)	0.09*** (0.02)
R ²	0.94	0.82	0.86	0.60	0.49	0.99	0.94
Observations	38,730	172,975	201,184	280,930	280,930	55,346	41,778
<i>Panel B: Shift-share instrument</i>							
Cartel member	1.13** (0.56)	2.25** (0.87)	1.41*** (0.44)	0.36** (0.14)	0.24*** (0.07)	0.77*** (0.22)	0.93* (0.49)
R ²	0.94	0.82	0.86	0.60	0.49	0.99	0.94
First-stage F	11.3	33.5	25.6	28.1	28.1	86.5	18.4
Observations	38,730	172,975	201,184	280,930	280,930	55,346	41,778
<i>Panel C: Ideal experiment (districts split by a law border)</i>							
Cartel member	0.84 (0.57)	2.86*** (1.05)	1.13** (0.45)	0.36*** (0.13)	0.21** (0.09)	1.66*** (0.26)	1.53** (0.75)
R ²	0.95	0.83	0.87	0.55	0.47	0.99	0.95
First-stage F	5.8	20.7	23.3	18.1	18.1	67.2	7.5
Observations	7,940	35,071	39,471	54,084	54,084	12,761	10,337
<i>Panel D: Recentered</i>							
Cartel member	1.13** (0.56)	2.25** (0.86)	1.41*** (0.44)	0.36** (0.14)	0.23*** (0.07)	0.77*** (0.22)	0.93* (0.49)
R ²	0.94	0.82	0.86	0.60	0.49	0.99	0.94
First-stage F	11.4	33.8	25.7	28.3	28.3	85.4	18.3
Observations	38,730	172,975	201,184	280,930	280,930	55,346	41,778
<i>Panel E: Recentered, reversals only</i>							
Cartel member	0.53 (0.49)	1.82* (1.00)	1.42*** (0.53)	0.45*** (0.16)	0.24** (0.10)	-0.14 (1.46)	1.23 (2.27)
R ²	0.94	0.82	0.86	0.60	0.49	0.99	0.94
First-stage F	13.1	19.5	16.4	17.4	17.4	1.4	0.8
Observations	38,730	172,975	201,184	280,930	280,930	55,346	41,778
Firms	6,453	16,038	21,979	25,817	25,817	4,138	3,902
Years	51	51	51	52	52	52	52
Outcome def.	(log)	(log)	(log)	(0/1)	(0/1)	(log)	(log)
Outcome mean	13.95	11.16	13.43	0.07	0.05	15.49	6.41
Standard errors	Industry	Industry	Industry	Industry	Industry	Industry	Industry
Sample	Statement	Statement	Capital	Full	Full	Operations	Operations
Firms observed pre- and post-1897	695	2,871	4,120	831	831	887	184
Firm fixed effects	✓	✓	✓	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓	✓	✓	✓

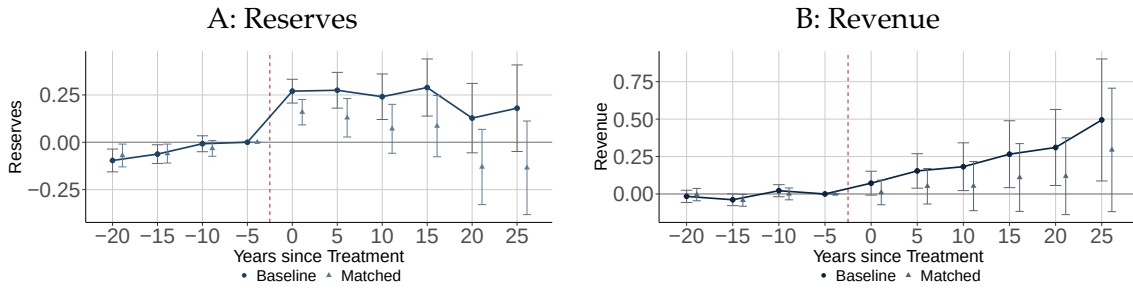
Note. Table presents results of estimating equation (9) by two-stage least squares. Cartel membership is an indicator equal to one from the first documented year of cartel membership of the firm onward, instrumented by a shift-share of court rulings: the pro-cartel decisions of the Imperial Court through 1913. The shift-share instrument is the sum of the pro-cartel decisions of the Imperial Court through 1913, weighted by the share of the cartel cases of the deciding senate that arose in the law region of firm i , accumulated to year t and then as the logarithm of one plus the sum. Panel A reports OLS on the same sample; Panel B the shift-share instrument; Panel C the shift-share instrument with districts split by a law border, with district-by-year fixed effects; Panel D the instrument recentered on non-cartel business rulings; and Panel E the recentered instrument built from lower-court reversals only. The first-stage F -statistic (cluster-robust) is reported per panel and column, and the row “Firms observed pre- and post-1897” counts the firms whose outcome is observed on both sides of the ruling. Outcomes are revenue, reserves and capital, exports and patents, and production and employment, as introduced in Section 4; each column is estimated on the firm-years for which its outcome is observed (the Sample Observations are at the firm-year level; the numbers of firm-years, firms, and years are shown in the table. The Outcome def. row gives the scale of the outcome: (0/1) an indicator, (log) the logarithm, (log 1+x) the logarithm of one plus the count, (%) a percentage. Standard errors are clustered by town and industry. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

5.3 Financing and Governance

We next examine financing and governance outcomes. Prediction 1.1 implies that, if cartel rents relaxed a borrowing constraint, members should show higher revenue, reserves, and capital expenditure, but not necessarily higher dividends. The association between membership and expansion should also be stronger where required outlays are large and external finance is scarce.

Financing. Table 3 reports results from estimating equation (9) with the two remaining financing outcomes as dependent variables; revenue and reserves appear in Table 1 (columns 1 and 2). In years of cartel membership, the dividend-rate coefficient is -0.48 percentage points, with a standard error of 0.15, against a mean rate of 5.50 percent (column 1), and capital expenditure is about 22 percent higher (column 2). Both coefficients are significant at the 1% level. In Table 1, reserves are about 20 percent higher, significant at the 1% level, and revenue about 4 percent higher, not statistically significant. Figure 6 reports the event-study estimates for reserves and revenue; both rise after cartel entry. These findings are consistent with the internal-financing mechanism described in Section 3.2.

Figure 6: Cartel Membership and Financing: Event Study



Note. Figure presents results of estimating equation (10), with 95% confidence intervals, in 5-year bins of years relative to the first year of cartel membership; the bin before it is the reference. Panels: reserves (A) and revenue (B), as introduced in Section 4, in logarithms. Standard errors are clustered at the firm level.

Governance ties. Table 4 reports results from estimating equation (9) with the four board outcomes as dependent variables. In years of cartel membership, firms have more interlocking board members, more employee representatives on the board, and more bank-affiliated and more state-affiliated board members (columns 1 to 4). All four coefficients are significant at the 1% level. Employee representatives sit on supervisory boards only after the works-council legislation of 1920–22, so column 2 draws on the later years. Members also have more board members with

Table 3: Cartel Membership, Payout, and Capital Expenditure

	Payout	Investment
	Dividend Rate	Capital expenditure
	(1)	(2)
Cartel Member	-0.48***	0.20***
	(0.15)	(0.06)
R ²	0.50	0.62
Observations	288,669	28,605
Firms	20,776	5,887
Years	52	51
Outcome def.	(%)	(log)
Outcome mean	5.50	13.30
Standard errors	Firm	Firm
Sample	Dividend	Investment
Firm fixed effects	✓	✓
Year fixed effects	✓	✓

Note. Table presents results of estimating equation (9). Outcomes are the dividend rate, in percent of share capital, so its coefficient is in percentage points, and capital expenditure, in logarithms, as introduced in Section 4; each column is estimated on the firm-years for which its outcome is observed (the Sample row). Observations are at the firm-year level; the numbers of firm-years, firms, and years are shown in the table. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

a scientific or engineering title, reported separately in Appendix Table E.14. In the event-study estimates, each association appears after cartel entry (Figure 7). Denser bank ties are consistent with the role of universal banks as creditors and board members in large investments (Hilferding, 1910; Gerschenkron, 1962; Fohlin, 2005). Denser state ties are consistent with the procurement relationships documented in Section 5.4.

Heterogeneity. We next examine heterogeneity by industry capital intensity (Prediction 1.2).⁶² Capital intensity, measured as investment relative to value added in Manova (2013), proxies the scale of required outlays; it does not measure financing constraints directly. We split industries at the cross-industry median.⁶³ Table 5 interacts cartel membership with an indicator for industries above the median. The interaction is positive for all five outcomes, significant at the 1% level for exporting and at the 5% level for the others (columns 1–5). For employment, the association

⁶²Appendix E.6 reports instrumented estimates, capital-intensity splits, and alternative board measures for the financing and board outcomes.

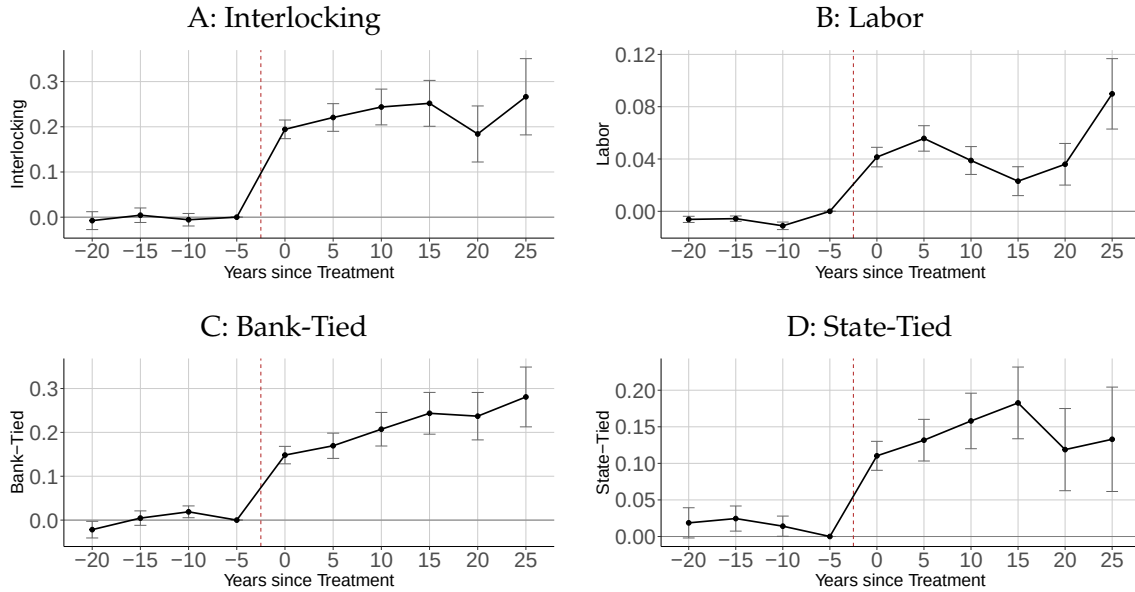
⁶³Capital intensity is one of the industry characteristics introduced in Appendix D.2; firms in industries without a value enter the below-median group.

Table 4: Cartel Membership and Board Composition

	Interlocking (1)	Labor (2)	Bank-Tied (3)	State-Tied (4)
Cartel Member	0.25*** (0.01)	0.04*** (0.00)	0.19*** (0.01)	0.15*** (0.01)
R ²	0.73	0.31	0.70	0.71
Observations	281,296	281,296	281,296	281,296
Firms	26,023	26,023	26,023	26,023
Years	52	52	52	52
Outcome def.	(log 1+x)	(log 1+x)	(log 1+x)	(log 1+x)
Outcome mean	1.30	0.03	0.44	0.45
Standard errors	Firm	Firm	Firm	Firm
Sample	Full	Full	Full	Full
Firm fixed effects	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓

Note. Table presents results of estimating equation (9). Outcomes are the numbers of interlocking, employee-representative, bank-tied, and state-tied board members, as introduced in Section 4, each as the logarithm of one plus the count. Observations are at the firm-year level; the numbers of firm-years, firms, and years are shown in the table. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

Figure 7: Cartels and Board Composition



Note. Figure presents results of estimating equation (10), with 95% confidence intervals. Panels: interlocking (A), employee-representative (B), bank-tied (C), and state-tied (D) board members, as introduced in Section 4, each as the logarithm of one plus the count. Standard errors are clustered at the firm level.

is larger in industries above the median than below it. The results are strongest for exporting, patenting, and employment, and are consistent with a larger role for coordination where required

outlays were greater.

Table 5: Cartel Membership and Firm Development, by Capital Intensity

	Earnings	Investment		Upgrading		Scale	
	Revenue	Reserves	Capital	Exports	Patents	Production	Employment
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Cartel Member	-0.01 (0.05)	0.09* (0.04)	0.18*** (0.03)	0.04*** (0.01)	0.00 (0.00)	0.01 (0.03)	0.07** (0.03)
Cartel Member $\times$ Capital intensity	0.08 (0.06)	0.17*** (0.05)	0.15*** (0.04)	0.04*** (0.01)	0.05*** (0.01)	0.18*** (0.05)	0.01 (0.03)
R ²	0.94	0.82	0.86	0.60	0.49	0.99	0.94
Observations	38,740	172,979	201,192	281,296	281,296	55,346	41,778
Firms	6,454	16,041	21,985	26,023	26,023	4,138	3,902
Years	51	51	51	52	52	52	52
Outcome def.	(log)	(log)	(log)	(0/1)	(0/1)	(log)	(log)
Outcome mean	13.95	11.16	13.43	0.07	0.05	15.49	6.41
Standard errors	Firm	Firm	Firm	Firm	Firm	Firm	Firm
Sample	Statement	Statement	Capital	Full	Full	Operations	Operations
Firm fixed effects	✓	✓	✓	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓	✓	✓	✓

Note. Table presents results of estimating equation (9), with the treatment interacted with an indicator for industries above the cross-industry median of capital intensity. Cartel Member is the coefficient for firms in industries below the median and the interaction row the additional coefficient above median firms in industries without a value enter the below-median group. Outcomes are exporting, patenting, output, employment, and capital, as introduced in Section 4. Observations are at the firm-year level; the numbers of firm-years, firms, and years are shown in the table. The Outcome def. row gives the scale of each outcome: (0/1) an indicator, (log) the logarithm, (log 1+x) the logarithm of one plus the count, (%) a percentage. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

The results presented in this subsection suggest that cartel membership, on average, is associated with higher investment and retained earnings, and with higher profit but not higher dividends. Organizationally, cartel members have denser interlocking, labor, bank, and state ties, and more board members with scientific or engineering titles. The expansion documented in Section 5.1 is also concentrated in capital-intensive industries. Taken together, these results are consistent with a mechanism in which cartels sustained investment in the face of financing frictions.

5.4 Cartel Members in the War Economy

Contemporary support for industrial coordination was framed partly in terms of national economic strength, and historical accounts suggest that cartel-backed internal financing became especially relevant during the First World War (Section 2.2). We therefore ask whether cartel members were more likely to be involved in the war economy of 1914–1918, when external finance was scarcest (Prediction 1.2).

We use the war-economy records introduced in Section 4.1 and compare cartel members and

firms outside cartels in the 1913 cross-section of 5,732 firms. The outcomes indicate whether a firm later held a military procurement contract, received a secret war patent, or placed a director on a war board. Table 6 regresses each outcome on cartel membership by 1913, controlling for three-digit industry fixed effects and for firm size and listing status in 1913. Cartel membership is associated with a 4-percentage-point higher probability of holding a military procurement contract, against a mean of 0.12 (column 1). This coefficient is significant at the 5% level. The associations with secret war patents and war-board directorships are smaller but positive and also significant at the 5% level (columns 2 and 3). These cross-sectional estimates show that cartel members were more frequently represented in the observed institutions of wartime production; they do not identify a causal effect of cartelization.

Table 6: Cartel Membership in 1913 and War-Economy Involvement

	War Procurement (1)	Secret War Patent (2)	War Board (3)
Cartel Member by 1913	0.039*** (0.014)	0.028** (0.011)	0.031** (0.015)
R ²	0.36	0.20	0.06
Observations	5,732	5,732	5,732
Industries	156	156	156
Outcome def.	(0/1)	(0/1)	(0/1)
Outcome mean	0.125	0.031	0.052
Standard errors	Industry	Industry	Industry
Controls	✓	✓	✓
Industry fixed effects	✓	✓	✓

Note. The sample is one observation per firm in the 1913 cross-section, in 156 three-digit industries. Each column regresses the indicator named in the column on an indicator of cartel membership by 1913, with three-digit industry fixed effects and controls (Controls) for listing status; firm size is not controlled, because size is itself a cartel outcome. Outcomes are the three indicators of war-economy involvement, as introduced in Section 4. Standard errors are clustered by three-digit industry. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

6 Downstream and Aggregate Evidence

6.1 Downstream Effects

Predictions 2.1 and 2.2 concern firms that purchase inputs from cartelized industries. Upstream markups may raise their costs, while later cost reductions or negotiated rebates may offset that burden. We examine whether the association between upstream cartel exposure and downstream

activity changed around the spread of state-mediated cross-sector bargaining. Historical evidence presented in Section 2.2 dates the spread of such agreements to the adversarial hearings of 1904, which brought cartels and their customers into mediated bargaining over prices and rebates. This suggests an analysis that separately examines exposure through input links that such agreements governed and through those they did not.

We first define exposure to cartelized inputs. The cartel exposure of firm i in industry s and year t is

$$Exposure_{it} = \sum_{s' \neq s} \omega_{ss'} CartelShare_{s't}, \quad (11)$$

where $\omega_{ss'}$ is the share of the inputs of industry s supplied by industry s' , from the input–output table of Section 4.1, and $CartelShare_{s't}$ is the size-weighted share of the firms of industry s' that are cartel members in year t .⁶⁴ Exposure is high when a large share of a firm’s inputs comes from heavily cartelized industries. Its sample mean is 0.60 and its standard deviation is 0.34. We report estimates per standard deviation.

We first estimate equation (9) in the full sample, with cartel exposure as the treatment. Throughout, we control for the firm’s own cartel membership. Panel A of Table 7 reports the results for the five main firm outcomes.

Pooled over the sample, exposure is positively associated with every outcome (Panel A). The associations with exporting and patenting are statistically significant, at the 5% and 1% levels respectively, against means of 0.07 and 0.05 (columns 1 and 2). The output, employment, and capital associations are positive but not statistically significant (columns 3–5).

In Table 7, Panel B, we split exposure by whether the firm’s cartelized input links were governed by a cross-sector agreement, following the state-backed negotiations that spread around 1904. Through input links without an agreement, higher exposure is associated with lower output, employment, and capital (columns 3–5). Through links under an agreement, it is associated with higher output, employment, and capital, and with higher exporting and patenting (columns 1 and 2). The contrast between governed and ungoverned links holds across the outcomes.

The history and model suggest two possible forces underlying this change. First, under Proposition 1, period-2 upstream prices are attenuated as cartel-financed investment lowers cost, and

⁶⁴The results are similar when we construct cartel shares with equal weights or with firm-size weights fixed before cartel entry, so that exposure is not weighted by potentially post-treatment size.

they might even fall below competitive levels. Second, Proposition 2 shows how agreements over rebates, discounts, and other terms can reduce downstream distortions while preserving horizontal coordination. The state-mediated negotiations beginning in 1904 provide a historical counterpart to the second mechanism, although the empirical design does not separately identify either channel. The estimates presented in Table 7 are consistent with a historical expansion of cross-sector bargaining: exposure is negatively associated with downstream upgrading and scale through input links without a cross-sector agreement and positively associated with them through governed links. Although the design cannot distinguish vertical contracting from other differences between governed and ungoverned links, this pattern accords with Prediction 2.2.

Table 7: Cartel Exposure and Firm Development

	Earnings	Investment		Upgrading		Scale	
	Revenue	Reserves	Capital	Exports	Patents	Production	Employment
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
<i>Panel A: Pooled</i>							
Cartel Exposure	-0.01 (0.11)	0.48*** (0.10)	-0.06 (0.05)	0.05*** (0.01)	0.03*** (0.01)	-0.13 (0.10)	0.06 (0.10)
R ²	0.94	0.82	0.86	0.60	0.49	0.99	0.94
<i>Panel B: By vertical contract</i>							
Cartel Exposure × No Vertical Contract	-0.05 (0.11)	0.33*** (0.10)	-0.11** (0.05)	0.03** (0.01)	0.02** (0.01)	0.03 (0.09)	0.06 (0.10)
Cartel Exposure × Vertical Contract	0.19 (0.17)	0.99*** (0.13)	0.10 (0.07)	0.10*** (0.02)	0.06*** (0.01)	1.22*** (0.18)	0.05 (0.14)
R ²	0.94	0.82	0.86	0.60	0.49	0.99	0.94
Observations	38,729	172,970	201,170	280,887	280,887	55,346	41,778
Firms	6,452	16,036	21,973	25,807	25,807	4,138	3,902
Years	51	51	51	52	52	52	52
Outcome def.	(log)	(log)	(log)	(0/1)	(0/1)	(log)	(log)
Outcome mean	13.95	11.16	13.43	0.07	0.05	15.49	6.41
Standard errors	Firm	Firm	Firm	Firm	Firm	Firm	Firm
Cartel Member	✓	✓	✓	✓	✓	✓	✓
Firm fixed effects	✓	✓	✓	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓	✓	✓	✓

Note. Table presents results of estimating equation (9) with cartel exposure in place of the treatment. Cartel exposure is defined in equation (11); own membership is controlled for throughout (Cartel Member row). Panel A pools exposure over the sample; Panel B splits the sample by whether the cartelized input links were governed by a cross-sector agreement, following the state-backed negotiations that spread around 1904. Outcomes are exposure to patenting, output, employment, and capital, as introduced in Section 4; each column is estimated on the firm-years for which its outcome is observed. Observations are at the firm-year level; the numbers of firm-years, firms, and years are shown in the table. The Outcome def. row gives the scale of the outcome: (0/1) an indicator, (log) the logarithm, (log 1+x) the logarithm of one plus the count, (%) a percentage. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

6.2 Market Structure and District Employment

Prediction 3 concerns districts and markets. Cartel rents may discourage entry while supporting activity among incumbents. We examine local industrial employment in the censuses and entry, exit, and concentration in the firm panel aggregated to markets.

District employment. We first consider local industrial employment. Using data from the five industrial censuses between 1882 and 1933 introduced in Section 4.1, we combine census employment with the firm panel at the level of the district and census wave, 437 cells over 89 districts. We estimate

$$Emp_{dt} = \gamma Cartel_{dt} + \mathbf{X}_{dt}'\Gamma + \alpha_d + \delta_t + \varepsilon_{dt}, \quad (12)$$

where Emp_{dt} is census employment in district d at census wave t and $Cartel_{dt}$ is the number of cartel-member firms, employment in logarithms and the firm count as the logarithm of one plus the count. The control $\mathbf{X}_{dt}$ is the logarithm of one plus the total number of firms, a measure of local industrial scale. Column 1 includes district fixed effects and the scale control; column 2 includes district and census-wave fixed effects without the control; and column 3 includes both sets of fixed effects and the control. Standard errors are clustered by district. In column 3, the elasticity is 0.18 (standard error 0.04). Within a district, a census wave with 10 percent more cartel-member firms thus records about 1.8 percent more employment, conditional on the total number of firms.

We conduct a descriptive scaling exercise to express the estimated elasticity relative to the observed change in total employment between 1882 and 1933. Considering the most restrictive specification in Table 8, column 3, we scale this coefficient by the observed increase in cartel-member firms over our sample period and compute its employment-weighted aggregate over all districts. The resulting decomposition accounts for 27% of the realized change in district employment.

Entry, exit, and concentration. We then turn to market dynamics. We aggregate the firm panel to the level of a market, a NACE three-digit industry by district cell, and estimate

$$Y_{mt} = \beta CartelShare_{m,t-1} + \alpha_m + \delta_t + \varepsilon_{mt}, \quad (13)$$

where Y_{mt} is, in turn, the logarithm of one plus the number of entrants, the logarithm of one plus the number of exits, the survival rate, or the Herfindahl index of market m in year t ; $CartelShare_{m,t-1}$ is the size-weighted share of the firms in the market that belong to a cartel, lagged one year; and α_m and δ_t are market and year fixed effects. We cluster standard errors by market. The sample covers 93,558 market-years in 5,140 markets for entry, exit, and survival, and the market-years with a defined Herfindahl index for concentration. Table 9 reports the results. A higher lagged cartel share is associated with fewer entrants (column 1) and fewer exits (column 2), with a higher share of incumbents surviving to the next year (column 3), and with a higher Herfindahl index (column 4). The entry, exit, and concentration coefficients are significant at the 1% level, and the survival coefficient at the 5% level. The magnitudes are small. A cartel share higher by one standard deviation, 0.23, is associated with about 0.5 percent fewer entrants and 1.1 percent fewer exits in the following year. It is associated with a survival rate higher by 0.21 percentage points, against a mean of 94.89 percent, and with a Herfindahl index higher by 0.01, about 2% of its mean of 0.72.

In sum, the district and market estimates point to an expansion concentrated among incumbents. Districts with more cartel-member firms record higher employment, while markets with larger cartel shares experience slightly less entry and exit, greater incumbent survival, and higher concentration.

Table 8: Cartel Firms and Employment

	Employment		
	(1)	(2)	(3)
Cartel Firms	0.12*** (0.03)	0.19*** (0.05)	0.18*** (0.04)
R ²	0.90	0.96	0.96
Observations	437	437	437
Outcome def.	(log)	(log)	(log)
Outcome mean	11.09	11.09	11.09
Standard errors	District	District	District
Market size controls	✓		✓
District FE	✓	✓	✓
Wave FE		✓	✓

Note. Observations are district-by-census-wave cells over the 5 industrial censuses of 1882, 1895, 1907, 1925, and 1933, a district being the aggregation level above counties in Imperial Germany. The outcome is the logarithm of census employment in the district, summed over industries and counties. Cartel Firms is the logarithm of one plus the number of firm-panel firms in the district at the census wave that are cartel members; Total Firms is the same count over all firm-panel firms and enters as a control for local industrial scale. Columns vary the fixed effects and the control. Standard errors are clustered by district. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

Table 9: Cartel Share and Market Entry, Exit, Survival, and Concentration

	Entrants (1)	Exits (2)	Survival Rate (3)	Market HHI (4)
Cartel Share in Market (t-1)	-0.02*** (0.00)	-0.05*** (0.01)	0.89*** (0.34)	0.06*** (0.01)
R ²	0.27	0.26	0.23	0.74
Observations	93,558	93,558	93,558	93,558
Markets	5,140	5,140	5,140	5,140
Years	51	51	51	51
Outcome def.	(log 1+x)	(log 1+x)	(%)	(share)
Outcome mean	0.12	0.16	94.89	0.72
Standard errors	Market	Market	Market	Market
Market fixed effects	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓

Note. Observations are market-years, a market being a NACE three-digit industry by district cell. Entrants and exits enter as the logarithm of one plus the count, survival as the percentage of active firms not exiting that year, and concentration as the Herfindahl index of firm size. The cartel share of the market enters lagged one year. All columns include market and year fixed effects. Standard errors are clustered by market. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

7 Conclusion

In this paper, we study legally enforceable cartels in Germany between 1882 and 1933. We examine their effects on cartel members, downstream firms, and broader industrial outcomes, using staggered cartel entry across firms and an unanticipated court decision that shifted the legal cost of cartel contracting. Within firms, cartel membership was followed by increases in exporting, patenting, output, employment, and capital. Our mechanism analysis is consistent with a model in which market power can relax financing constraints by increasing internal funds for investment, at the cost of static distortions. Cartel coordination became increasingly coupled with bargaining across stages of production. Consistent with this, a negative association between exposure to cartelized inputs and downstream outcomes attenuated after cross-sector bargaining became common.

Horizontal and vertical negotiation thus widened the set of interests brought into contractual coordination, substituting imperfectly for missing financial and vertical markets (Coase, 1960; Ostrom, 1990).⁶⁵ This broadened the scope of coordination within what increasingly resembled a corporatist “national system” in Germany (Schmitter, 1974).⁶⁶ Our findings suggest that this system supported productive investment and expansion while also being associated with greater involvement in the war economy, higher concentration, and lower entry.

Two limits to this form of economic organization follow from a welfare perspective. The first limit arose from the national scope of the arrangements. Bargaining could address conflicts among represented domestic firms and sectors, but it did not internalize costs borne by foreign producers, governments, or consumers. British and French authors writing during the First World War accordingly viewed German industrial organization as both a source of national strength and a threat to foreign producers and states (Hauser, 1915).⁶⁷ The significance of this boundary would

⁶⁵In the Coasean benchmark, frictionless bargaining and complete property rights make intermediation unnecessary. In practice, parties have to observe relevant states, verify claims, commit to terms, implement transfers, and potentially select among multiple feasible bargains (Samuelson, 1995). This gives a role to state facilitation of negotiation, ensuring the commitment required to make feasible bargains implementable.

⁶⁶For industry, state capacity functioned as a production input: contract enforcement supplied the credible commitment needed to sustain decentralized agreements. For the state, delegating coordination to firms mobilized industrial capacity without requiring public financing or direct selection of recipient firms. The arrangement thus economized on fiscal and administrative capacity by backing private coordination with public enforcement authority (Weber, 1919; Besley and Persson, 2011). It also gave the state contingent access to the resulting industrial capacity, most visibly during wartime (Kang et al., 2025).

⁶⁷Interwar international cartels and negotiations under the League of Nations later brought some foreign interests within the bargaining community (Hewitt, 2024), although national policymakers retained limited incentives to weigh costs borne abroad.

only increase with the renewed mobilization of German industry before and during the Second World War.⁶⁸ The second limit concerned the future. Future firms, sectors, and technologies could not bargain with incumbents over the institutions being created. The same arrangements that supported investment and industrial expansion could therefore entrench established producers and impede later adjustment (Olson, 1982; Fernández and Rodrik, 1991).⁶⁹

The welfare effects of negotiated industrial governance therefore depend on who participates. Coordination may support incumbent investment when finance and contracting are limited, but it may also impose costs on downstream firms, foreign interests, and future entrants. Its value depends on both the agreements it sustains and the interests those agreements exclude (Jonas, 1984; Habermas, 1996).

⁶⁸The case of synthetic nitrogen illustrates this dual use (Horkheimer and Adorno, 1947): the same process that expanded the supply of agricultural fertilizer also supplied nitrogen for munitions, and Haber himself directed the German gas-warfare program (Smil, 2011).

⁶⁹The stabilizing effect on incumbents is already visible during our analysis period. Institutions that supported German catch-up may therefore also have contributed to economic structures whose advantages proved less durable as technologies and comparative advantage changed. Recent evidence on the long-run reversal of regional fortunes within Germany is consistent with this possibility (Berbée et al., 2025).

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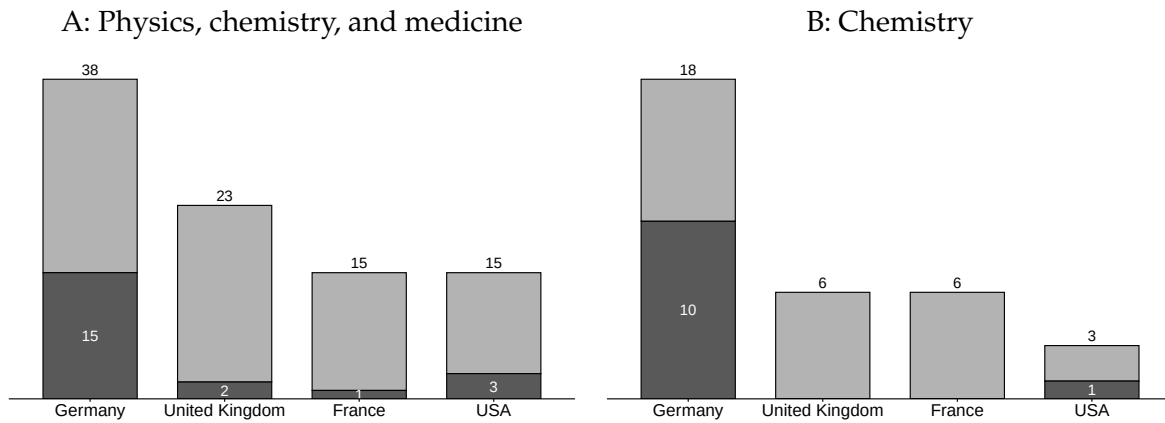
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A Figures and Tables

A.1 Figures

Figure A.1: Nobel Laureates by Country and Firm Affiliation, to 1939



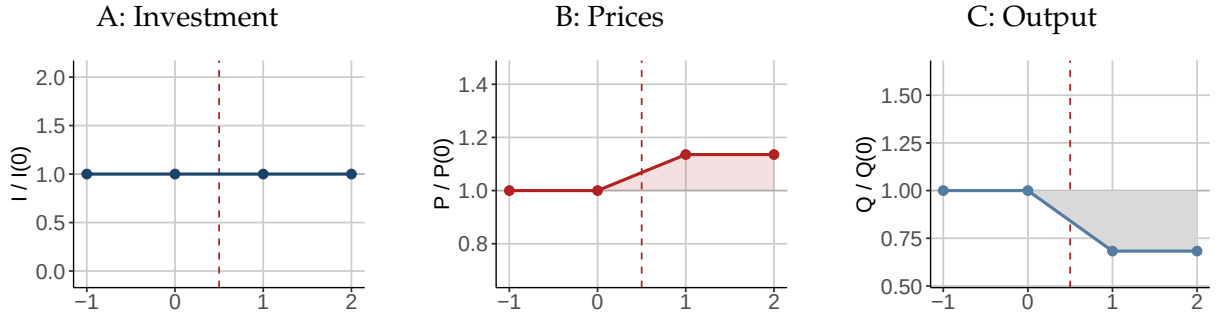
Note. Nobel science laureates through 1939, by country of origin for the four countries shown. Panel A covers physics, chemistry, and physiology or medicine; Panel B covers chemistry. The dark segment counts laureates with a documented industrial affiliation, including employment. German affiliations include BASF, Bayer, Hoechst, Siemens, and Zeiss.

Figure A.2: Chilean Nitrate Extraction, circa 1906



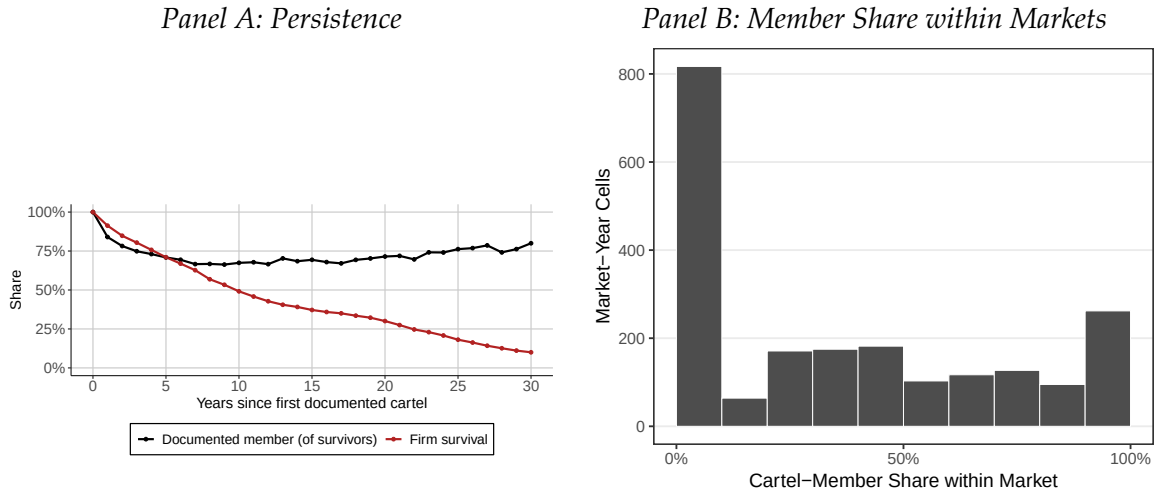
Note. Workers extracting caliche in the Atacama nitrate fields, the source of the natural Chilean sodium nitrate (saltpeter) on which European agriculture relied before synthetic ammonia fixation. Source: Album del Desierto (<https://www.albumdesierto.cl/>).

Figure A.3: Investment, Prices, and Output across Periods: Financially Unconstrained Sector



Note. The same calibration and axes as Figure 3, for a financially unconstrained sector that holds the full project, $I = \bar{I}$, throughout. Each series is relative to the same sector at $\kappa = 0$ (period 0); the dashed vertical line marks cartel formation. Investment does not respond (Panel A), and period-2 price (Panel B) and output (Panel C) stay at their period-1 levels, so the period-2 recovery of Figure 3 disappears.

Figure A.4: Cartel Membership: Persistence and Market Coverage



Note. Panel A plots years since a firm's first documented cartel membership. The black line is the share still documented as cartel members among firms still observed; the red line is the share still observed in the sample. Per-year membership is under-recorded. Panel B shows the distribution of the size-weighted cartel-member share within NACE three-digit-by-district markets under an absorbing membership definition. Each observation is a market-year; markets with fewer than three firms are omitted. Listed industrial firms, 1882–1933.

A.2 Tables

Table A.1: Summary Statistics

Variable	Mean	SD	Min	Max	N	Enters as
<i>Panel A: Treatment & Exposure</i>						
Cartel Member	0.06	0.24	0.00	1.00	372,584	(0/1)
Cartel Exposure	0.60	0.34	0.00	1.00	372,098	(share)
Cartel Exposure (Pre-1904)	0.38	0.29	0.00	0.93	372,098	(share)
Cartel Exposure (Post-1904)	0.21	0.23	0.00	0.83	372,098	(share)
Cartel Member by 1913	0.18	0.39	0.00	1.00	5,732	(0/1)
Legal-Region Ruling Stock	3.10	1.26	0.00	4.42	372,584	(count)
Same Law Region	0.07	0.23	0.00	0.88	372,584	(index)
<i>Panel B: Firm Outcomes</i>						
Revenue	7.57×10^7	6.01×10^8	9.33	9.94×10^9	38,935	(log)
Exports	0.07	0.25	0.00	1.00	281,296	(0/1)
Patents	0.05	0.22	0.00	1.00	281,296	(0/1)
<i>Panel C: Productive Capacity</i>						
Production	1.58×10^9	2.44×10^{10}	0.82	1.47×10^{12}	55,346	(log)
Employment	1,732.48	3,663.27	2.00	31,294.31	41,778	(log)
Capital	4.42×10^6	3.04×10^7	63.09	6.74×10^9	202,203	(log)
<i>Panel D: Mechanisms</i>						
Capital expenditure	5.14×10^6	2.48×10^7	0.07	1.02×10^9	28,749	(log)
Dividend Rate	6.95	28.09	0.00	1,000.00	289,996	
Reserves	1.71×10^6	2.17×10^7	0.00	3.64×10^9	173,942	(log)
<i>Panel E: Board Interlocks</i>						
Bank-Tied	0.92	1.65	0.00	38.00	281,296	(log 1+x)
State-Tied	0.99	1.88	0.00	65.00	281,296	(log 1+x)
Interlocking	3.87	4.39	0.00	146.00	281,296	(log 1+x)
Science-Tied	0.18	0.55	0.00	29.00	281,296	(log 1+x)
Labor	0.05	0.30	0.00	4.00	281,296	(log 1+x)
<i>Panel F: War Economy</i>						
WWI Procurement	0.12	0.33	0.00	1.00	5,732	(0/1)
Secret War Patent	0.03	0.17	0.00	1.00	5,732	(0/1)
War Board (WWI)	0.05	0.22	0.00	1.00	5,732	(0/1)
<i>Panel G: Market Structure</i>						
Entrants	0.12	0.87	0.00	135.00	93,558	(count)
Cartel Share in Market (t-1)	0.08	0.23	0.00	1.00	93,558	(share)
Exits	0.16	0.71	0.00	50.00	93,558	(count)
Market HHI	0.72	0.33	0.00	1.00	93,558	(index)
Survival Rate	94.89	18.33	0.00	100.00	93,558	
<i>Panel H: Controls</i>						
Firm Size	0.01	0.76	-4.38	3.18	5,732	(log)
Listed	0.19	0.39	0.00	1.00	5,732	(0/1)

B Historical Background

B.1 Additional Historical Evidence

This appendix presents supporting evidence for the historical account in Sections 2.1 and 2.2, following the order of the main text.

Late Industrialization and Financial Frictions

Germany industrialized late, behind the technological frontier.

- Contemporary and later accounts describe German producers as reliant on technology borrowed from Britain and France in the mid-nineteenth century (Veblen, 1915).

German manufactures entered world markets on price and imitation, prompting the 1887 origin label.

- The Merchandise Marks Act of 1887 required imports to be marked “Made in Germany” as a warning to British buyers (Williams, 1896).

The gap closed within a generation, and competition shifted to quality and technology.

- By 1913 Germany was the leading manufacturer on the European continent and approached Britain in world markets for manufactures (Hesse, 2023). British legislation moved from origin marking to the 1907 Patents and Designs Act with its working requirement, and then to the Dyestuffs Act of 1920 and the Safeguarding of Industries Act of 1921 (Parliament of the United Kingdom, 1907; 1920; 1921).

Reaching the frontier required investment at a new scale.

- Technological advance came to depend on organized laboratories and large integrated plants rather than individual inventors (Chandler, 1990; 2005).

Universities and industrial laboratories jointly produced frontier science, in industries of strategic weight.

- German chemists won a succession of early Nobel Prizes, many within industrial firms and their laboratories (Appendix Figure A.1); observers abroad noted the dependence on German supply of inputs such as potash and saltpeter (Williams, 1896).

External finance was costly, so firms financed expansion from retained profit.

- Equity issuance diluted founding-family control and bank lending was constrained by monitoring and collateral (Tilly, 1982); in chemicals before 1900 internal surpluses supplied more than half of expansion capital (Prion, 1931); one Rhenish ironworks capped its dividend at 5 percent and placed the remainder in reserve and equipment funds (Williams, 1896).

Wartime conversion was financed internally and coordinated through organized industry.

- At the AEG general meeting of 1915, Walther Rathenau argued that it would have been impossible to ask shareholders to risk 30 or 40 million marks on war contracts of uncertain outcome, and that industry drew its conversion to war production from silent reserves (Tschierschky and Borger, 1915, p. 913). The wartime raw-materials administration he designed allocated inputs through war corporations run by industrialists (Rathenau, 1918; Feldman, 1966).

The financing constraint persisted and tightened after the First World War.

- Wartime disruption and postwar inflation left liquid capital scarce (Whale, 1930; Brunnermeier et al., 2025).

Cartels and Their Legal Enforceability

Industrial expansion followed a broad liberalization of entry.

- The imperial trade code of 1869, extended across the Reich after unification, established freedom of trade, and the founding boom of the early 1870s raised the number of firms (Pierenkemper, 2007).

Post-1873 deflation compressed prices and margins into “ruinous competition.”

- Contemporaries contrasted unrestrained rivalry with stabilization and rationalization (Schmoller, 1906).

Firms responded through contractual coordination.

- Sales syndicates had operated in coal and salt since the 1820s and 1840s and spread through mining and heavy industry as prices fell (Marburg, 1964; Böse, 2018); contemporaries defined a cartel as an association among independent firms of the same trade (Liefmann, 1905).

For decades the legal status of cartel agreements was uncertain.

- No general cartel law existed; members who broke quotas could be expelled but were seldom compelled by courts to honor the agreement (Kestner, 1912; Nörr, 1994).
- The uncertainty was salient enough to reach general reference works: the contemporary entry on cartels in Meyers Konversations-Lexikon (1892, pp. 508–511) devotes half of its length to the unsettled question of whether cartel agreements were legally enforceable.

Fragmentation persisted even as private law became uniform.

- Courts applied common provisions to cartels unevenly, and association law differed by state (Zeller, 1895; Fischer, 1896; Guinnane, 2020).

A judicial turn made cartel contracts enforceable.

- In 1897 the Imperial Court upheld a Saxon wood-pulp cartel contract as valid and enforceable, placing freedom of contract above an unrestricted freedom to compete (Nörr, 1994); contemporaries described the subsequent spread of cartels as arriving “like lightning” (Schäffle, 1898).

The ruling set a permissive baseline but left issues unresolved.

- Courts continued to differ over penalties, boycotts, rights of withdrawal, and public-policy limits, assessed case by case (Langhorst, 1926).

General codification arrived with the 1923 Cartel Decree.

- The decree created a specialized Cartel Court, required written agreements, and gave firms greater certainty while imposing few substantive limits (Goldbaum, 1924; Langhorst, 1926; Marburg, 1964).

Some firms moved to tighter forms of coordination.

- Profit-pooling *Interessengemeinschaften* joined operations and divided earnings short of merger, and by the 1930s more than half of industrial output was organized through such arrangements (Friedländer, 1921; Chandler, 1990).

The state tolerated cartels and pursued export-led growth.

- From the 1890s officials pursued export-led growth as national policy and valued cartels as instruments of national competition abroad (Gerber, 2001; Torp, 2010).

Concern about downstream burdens opened a channel of supervised negotiation.

- From the cartel inquiry of the 1900s the state convened adversarial hearings, tripartite proceedings giving downstream buyers a forum to press upstream suppliers (Reichsministerium des Innern, 1906); the steel syndicate held domestic prices above export prices and rebated exporting finishers (Webb, 1980).

The state supervised organized industry rather than prohibiting it.

- Germany rejected an American-style prohibition in favor of supervised self-administration (Langhorst, 1926; Marburg, 1964).

B.2 Case Studies

This appendix uses episodes from five industries (chemicals, electrical engineering, iron and steel, coal, and potash) to illustrate the framework developed in the main text.

The aim is to trace central cases that clarify plausible mechanisms. While there are several potential channels, we focus on how cartels can sustain prices above marginal cost, thereby relaxing financing constraints on long-horizon investment. Such investment may then reduce marginal cost, expand output, and lower prices. The resulting dynamic gain can, in principle, offset the static deadweight loss from price support.¹ No case traces the chain in full; the cases provide suggestive qualitative and quantitative evidence on its links. The central question is whether the additional profit financed productive investment or was extracted as rent.

The cases illustrate potential gains and costs. Coordination sometimes organized investment in new products or reallocated capacity in existing ones. In electric lamps, it instead reduced product durability. The cases are not a random sample: they cover prominent firms and industries with unusually rich records. They complement the firm-level estimates by documenting mechanisms at a resolution that the panel cannot observe.

B.2.1 Chemical Industry

The chemical industry accounted for a disproportionate share of German innovation during the period (Figure A.1). The institutional arrangements documented in Section 2.2 (cartel contracts, cross-sector negotiations, and state facilitation) are especially visible in the chemical industry. Between the 1890s and the formation of IG Farben in 1925, these institutions supported breakthrough research. Fritz Haber, Carl Bosch, Friedrich Bergius, Gerhard Domagk, and Paul Ehrlich all received Nobel Prizes for work conducted at cartel-affiliated firms.

The *Dreibund* of 1904. The German chemical industry was among the most cartelized sectors of the German economy. Its organization reflected the technological structure of coal-tar chemistry. Major innovations relied on common intermediates, cumulative process improvements, specialized scientific labor, and large fixed investments in laboratories and plants. These features made firms interdependent. A discovery in one product line could alter costs or opportunities in another, while upstream intermediates required scale and predictable demand. Cartel agreements therefore often did more than allocate markets. They organized product specialization, pooled profits, stabilized expectations, and financed research programs whose returns were uncertain and long delayed.

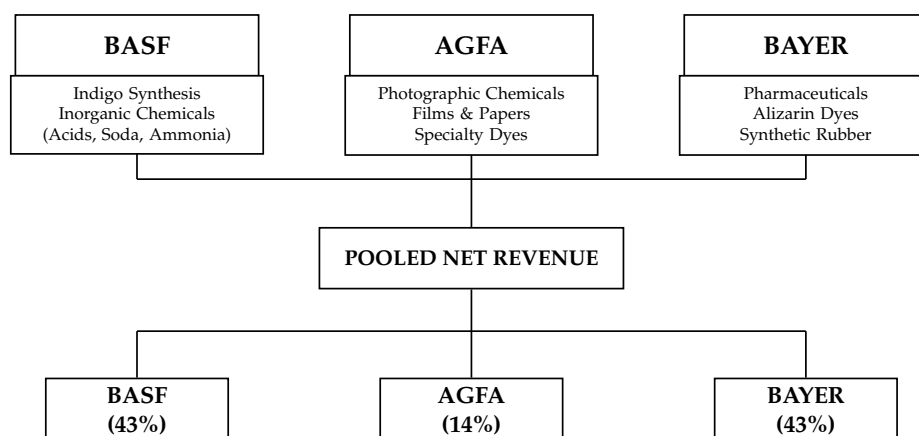
The coal-based industrial platform also linked dye firms to acids, alkalis, electrochemistry, coal, and eventually high-pressure nitrogen synthesis. By the end of the nineteenth century, German firms accounted for nearly all new dyestuff inventions, but dyes were only one output. Aniline-dye plants also produced sulfuric acid for fertilizers and chlorine, later used in chemical warfare. Many products therefore had both civilian and military uses.

The *Dreibund* of 1904 was a central institutional expression of this system. In 1904, the three leading dye producers (BASF, Bayer, and Agfa) formed the *Dreibund*, a profit-pooling and R&D-coordinating cartel (Abelshauser et al., 2004). The firms kept separate balance sheets and management, but pooled part of their operating profits, specialized by territory and product line, and

¹Appendix C formalizes the comparison: price coordination raises total surplus when the discounted social value of the additional investment it finances exceeds the sum of the static deadweight loss and the investment cost. In the model, coordination raises the price and contracts output in the short run; the price declines documented below appear in the displacement cases, where the synthetic product expanded the market.

jointly financed long-horizon research. Figure B.1 reproduces the organizational structure of the *Dreibund* from the contemporary cartel statutes.

Figure B.1: The Chemicals *Dreibund* (1904)



Note. The figure reconstructs the organization of the *Dreibund* among BASF, Bayer, and Agfa in 1904. Nodes denote member firms and contracting counterparties; edges denote profit pooling, R&D sharing, or product-specialization clauses. Source: authors' reconstruction from cartel statutes in the *Kartell-Rundschau* and secondary sources.

Synthetic Nitrogen: Haber–Bosch. Before the First World War, fixed nitrogen for fertilizer and explosives came mainly from sodium nitrate mined in Chile.²

By 1900, concern about natural nitrate supplies increased the value of fixing atmospheric nitrogen at industrial scale. The process required pressures and temperatures beyond existing equipment, and commercialization demanded a decade of scientific and engineering investment. No single firm possessed all the required technical and financial capabilities. In 1900, Wilhelm Ostwald offered his ammonia-synthesis process to BASF, Hoechst, and the Elberfeld works; BASF negotiated terms of 100,000 marks up front with royalties capped at 3.25 million marks, but Carl Bosch traced the reported ammonia yields to nitride contamination of the iron catalyst, and Ostwald withdrew his patent application (Johnson, 2022, pp. 82–87). In 1903, BASF subscribed only 0.2 million of the 2.0 million kronen offered to it in Sam Eyde's Norwegian arc-nitrogen venture.

The *Dreibund* coordinated the program. It financed roughly 20,000 catalyst trials from retained earnings, secured long-term coal contracts with the Rhenish–Westphalian Coal Syndicate, and contracted with specialized suppliers:

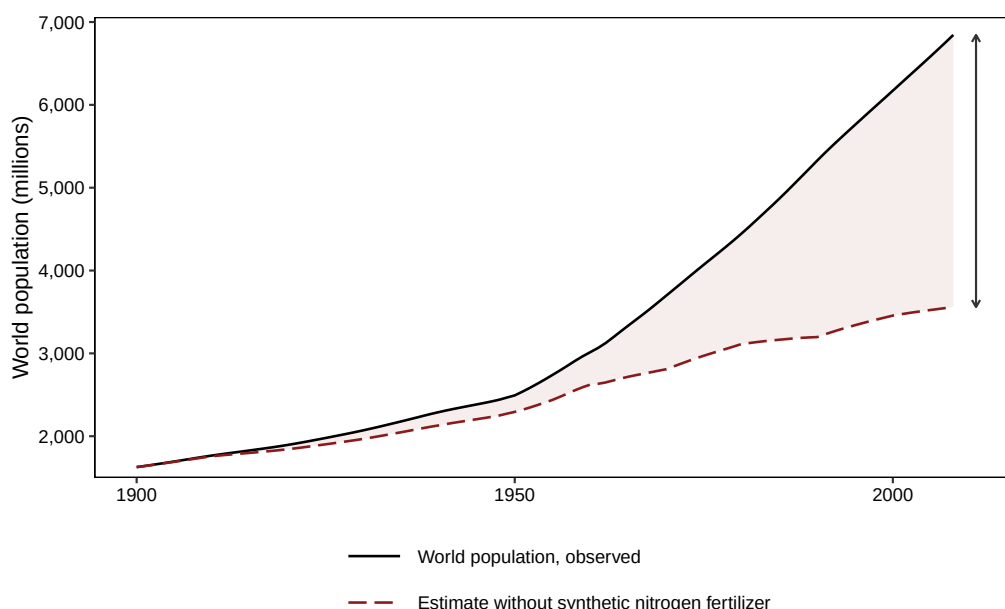
- **Mannesmann** supplied seamless steel tubes for the first high-pressure reactor prototypes.
- **Krupp** developed chromium steels that could withstand the ~200-bar operating pressure of the industrial Haber–Bosch reactor at Oppau.
- **Auergesellschaft** supplied the osmium catalyst used in the first effective laboratory synthesis; on Haber's advice, BASF bought Auer's osmium stock in 1909.
- **Linde** provided cryogenic gas-separation technology for the early hydrogen program.

²Chilean nitrate had itself displaced Peruvian guano, the earlier natural nitrogen source, whose export revenues underwrote the Peruvian state and its sovereign debt through the 1860s (Vizcarra, 2009). Chilean nitrate production was in turn organized through a sequence of legally enforceable producer cartels (Carrera, 2026).

- **Griesheim-Elektron** supplied hydrogen through its electrochemical chlor-alkali process.
- **The state** later provided loans and purchase guarantees for wartime expansion at Oppau.

Commercial production began in 1913. The Haber–Bosch process is estimated to sustain more than half of the world population today (Erisman et al., 2008; Smil, 2011; Ladha et al., 2016) (Figure B.2). By 1926, synthetic nitrogen generated roughly two-thirds of IG Farben’s operating profits. Haber received the 1918 Nobel Prize and Bosch the 1931 prize for work developed within this coordinated supply chain.

Figure B.2: Estimated Global Population with and without Haber–Bosch



Source: Erisman et al. (2008), *Nature Geoscience*.

Note. Observed world population and the population that Erisman et al. (2008) estimate could have been supported without synthetic nitrogen fertilizer are shown for 1900–2008. The shaded area is the population attributable to synthetic fertilizer. The estimate holds diets fixed at levels supportable without synthetic fertilizer and is therefore an accounting exercise, not a causal counterfactual. Smil (2011) obtains a similar magnitude.

IG Farben later invested 426 million Reichsmark in synthetic fuel from coal hydrogenation, using high-pressure methods related to those developed for nitrogen.

During the First World War, the British blockade cut off Chilean nitrate imports. The *Dreibund* then adapted the fertilizer process to produce nitrogen explosives for German munitions (Figure B.3).

Synthetic nitrogen displaced Chilean nitrate in the world market for fixed nitrogen. The displacement disrupted public finances in Chile. Nitrate export duties financed close to half of Chilean ordinary revenue during the two decades before 1914. Figure B.4 plots the nitrate share of ordinary revenue from 1880. The share stayed near one-half through the 1900s and then fell from the mid-1910s, first because of wartime market disruption and then because of synthetic competition in the 1920s. The fiscal base collapsed during the Depression: mining-tax revenue fell from 28 percent of GDP at the pre-Depression peak to 1 percent by 1932 (Lüders and Wagner, 2003).

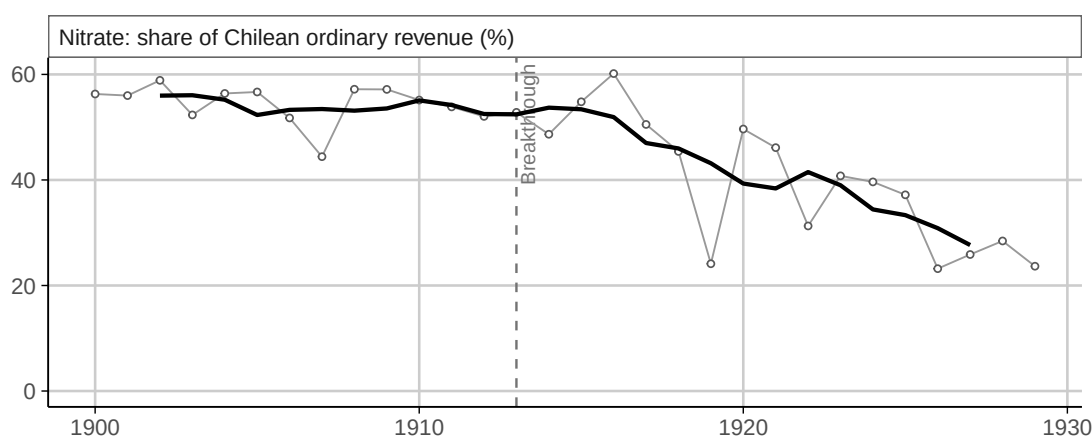
Cross-product spillovers. The high-pressure platform developed for nitrogen also produced adjacent products. At Leuna in 1923, the same reactors, catalysts, and coal-based synthesis gas

Figure B.3: The *Dreibund* and First World War Mobilization



Note. Photograph of Fritz Haber instructing military officers on nitrogen explosives during the First World War.

Figure B.4: Nitrate Share of Chilean Ordinary Revenue, 1880–1929

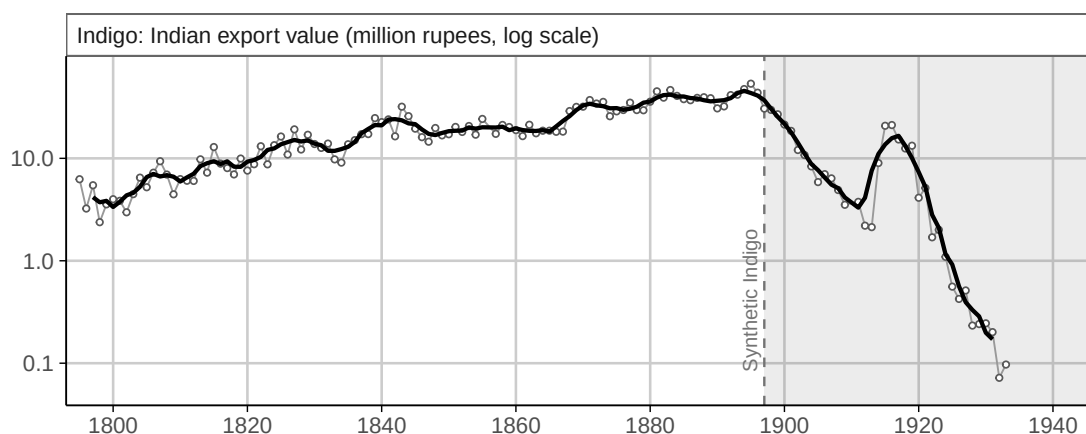


Note. Nitrate share of Chilean ordinary government revenue, percent, 1880–1929. The heavy line is a five-year moving average. The labeled series ends in 1929. The arrow marks the early-1930s collapse, documented on other denominators. The dashed line marks the 1913 Haber–Bosch scale-up, and the shaded region marks the years after the scale-up. Source: Hernández Cornejo (1930), via the *Album del Desierto* compilation (<https://www.albumdesierto.cl/estadis.htm>).

produced synthetic methanol. The high-pressure route from carbon monoxide and hydrogen remains the industrial basis of methanol production (Abelshauser et al., 2004). German synthetic methanol soon displaced the older wood-distillation route.³ BASF thereby reused capabilities financed by nitrogen research, generating economies of scope. Coordination also financed an earlier route to fixed nitrogen. The Cyanidgesellschaft, formed in 1899, pooled capital from Deutsche Bank, Siemens & Halske, and Degussa with the inventors' patents to develop calcium cyanamide through the Frank–Caro process. The consortium owned Bayerische Stickstoffwerke, which built the first plants (Chandler, 1990). Cartels then organized the market: a Karbidsyndikat from 1903, an international calcium-carbide syndicate from 1904, and a calcium-cyanamide sales association from 1908. The carbide route also yielded acetylene, a feedstock for later organic synthesis. Phar-

³Contemporary trade reporting recorded Canadian methanol exports falling from 118,300 gallons in 1924 to 19,800 gallons in 1926 as the synthetic product entered world markets.

Figure B.5: Indian Indigo Export Value, 1795–1934



Note. Annual value of Indian indigo exports, in nominal millions of rupees on a log scale, 1795/96–1933/34. The heavy line is a five-year moving average. The dashed line marks the 1897 commercial scale-up of synthetic indigo; shading begins with the scale-up. Source: Nadri (2016, pp. 211–215).

maceuticals drew on these capabilities indirectly. Salvarsan, introduced by Hoechst AG in 1910 as the first synthetic chemotherapeutic agent, used organic-chemistry intermediates supplied by Hoechst and Cassella. These firms were joined in a profit-pooling community of interest and supplied inputs to the research institute where Salvarsan was developed (Chandler, 1990). The link to coordination therefore runs through shared capabilities and pooled inputs.

BASF's acid production shows a similar sequence of process innovation. Rudolf Knietsch developed the contact process for sulfuric acid and brought it to industrial scale. After patenting the process in 1898, BASF used it for nearly all acid production by 1899. A contemporary account put its cost at one-third that of English chamber acid (Schultz, 1914; Haustein, 2017). The initial objective was fuming acid for dye synthesis. During the First World War, BASF coupled synthetic ammonia with Ostwald oxidation at Oppau. The first furnaces began operating in February 1915 under Reich purchase guarantees and loans, replacing blockaded nitrate (Fehr, 2009).

Dyestuffs. The indigo case combines coordinated research with coordinated export sales.

Natural indigo, grown chiefly in Bengal and Bihar for textile dyeing, was a major Indian export crop. Exports reached roughly 10,000 tons in 1895 (Nadri, 2016). Figure B.5 reports export value from 1795/96 onward.

BASF began synthetic-indigo research in 1880 and organized it contractually from the outset. A March 1880 contract acquired Adolf Baeyer's synthesis rights; an agreement with Hoechst followed in 1881; and BASF purchased another process in 1890.⁴ Development took about seventeen years and cost an amount comparable to BASF's share capital (Abelshauser et al., 2004).

The 1904 indigo agreement applied the *Dreibund* model to commercialization. Members pooled patents on four synthetic routes, specialized by product, designated BASF as the lead producer, induced Bayer to exit indigo, negotiated coal purchases jointly, and shared a U.S. sales office.

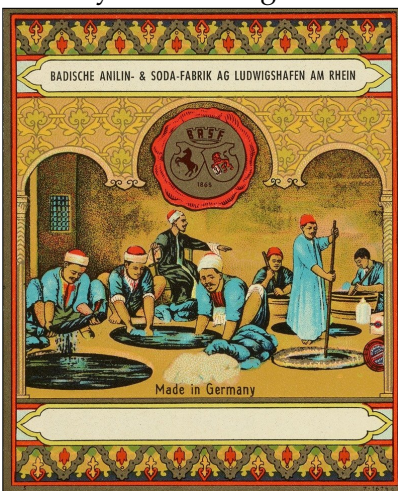
Figure B.6 shows how the cartel marketed synthetic indigo abroad.

The process reached commercial scale in 1897. Synthetic indigo was chemically identical to the natural dye, more uniform, and made at a marginal cost that fell with output.

⁴Annual reports of the BASF board of directors to the supervisory council, 1880–1910, BASF corporate archives. The 1898 report puts the outlay on the first indigo plants at 10 million marks.

Figure B.6: Synthetic Indigo and Cartel Export Advertising

A: BASF Synthetic Indigo Trade Card



B: Bayer Export Directory Ad, 1907



Note. Panel A shows a BASF trade card for synthetic indigo. Panel B shows a Bayer advertisement from the 1907 edition of *Kelly's Directory of Merchants, Manufacturers And Shippers of the World*. Sources: BASF corporate archives and *Kelly's Directory*.

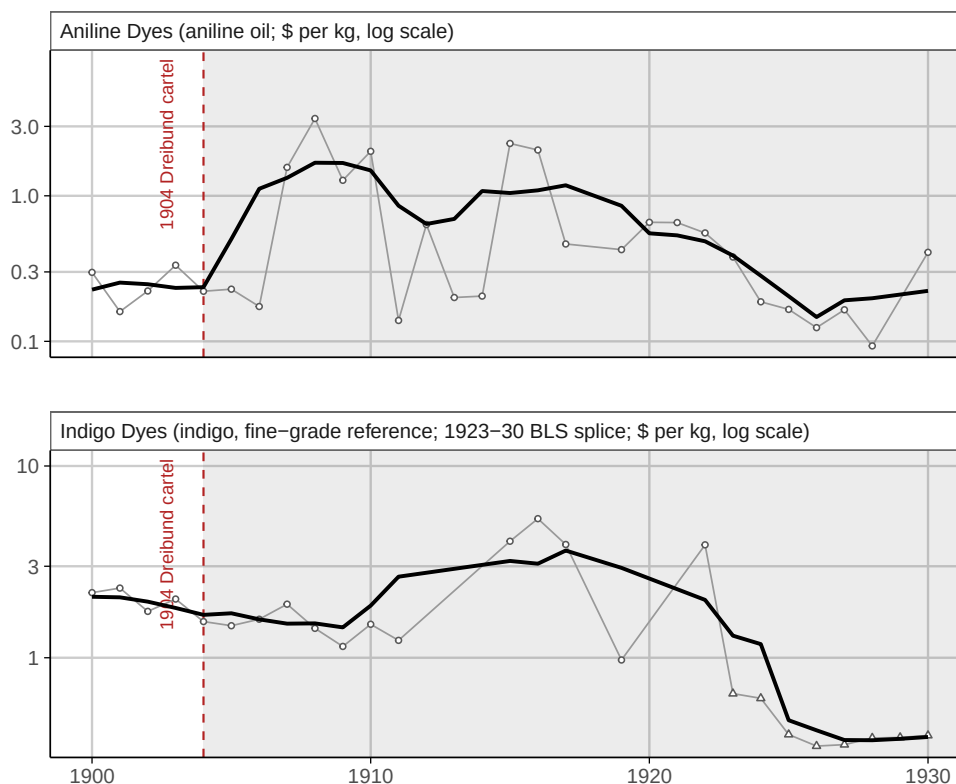
Synthetic indigo displaced Indian indigo from the world dye market within little more than a decade. By 1910, Indian exports had fallen about 90 percent, and German synthetic indigo dominated world markets (Nadri, 2016). Export value, measured in tens of millions of rupees for much of the previous century, fell to about 100,000 rupees by the early 1930s (Figure B.5). Indigo ceased to be a major export industry in the planting districts.

This displacement is visible in prices as well as in volumes. Figure B.7 reports fine-grade indigo and aniline oil, the principal coal-tar input into synthetic indigo. Beginning in 1923, the indigo series is extended with U.S. wholesale prices for synthetic paste. Indigo prices fell by nearly half within a decade of the 1897 launch and to a small fraction of their prelaunch level by the late 1920s. Within natural indigo, most of the decline occurred after the 1897 launch, not after the 1904 cartel agreement.

From Cartel to Merger: IG Farben (1925). By the mid-1920s, the *Dreibund* had expanded into an *Interessengemeinschaft* (community of interest) that included nearly all leading German chemical firms. In 1925, its members merged into IG Farben (Figure B.8). The sequence ran from an enforceable cartel contract in 1904, through cross-firm R&D and supply-chain integration from 1904 to 1913, to wartime mobilization from 1914 to 1918 and legal consolidation in 1925.

The internal organization of the merged firm closely mirrored the committee and profit-pooling logic of the *Dreibund* on a larger scale while maintaining high functional specialization and decen-

Figure B.7: Aniline Oil and Indigo Prices



Note. Real prices of aniline oil and indigo, in constant 1913 U.S. dollars per kilogram on a log scale, 1900–1930. Annual values from the *Chemiker-Zeitung* are year fixed effects from regressions of log real price on year, market-region, and grade indicators, evaluated at the fine reference grade and deflated by the U.S. consumer price index from the Jordà–Schularick–Taylor Macrohistory Database. Repeated quotations on the same page enter once. Thin lines connect annual values, open circles mark observations, and the heavy line is a five-year moving average; lines do not bridge gaps longer than six years. Triangles from 1923 onward are U.S. wholesale prices for synthetic-indigo paste, scaled to the overlap with the German quotations. Papermark quotations without a printed month are excluded from 1914 through 1925. The dashed line marks the 1904 *Dreibund*; shading begins in 1904. The indigo-price peak occurs in 1916, so wartime disruption overlaps the cartel period.

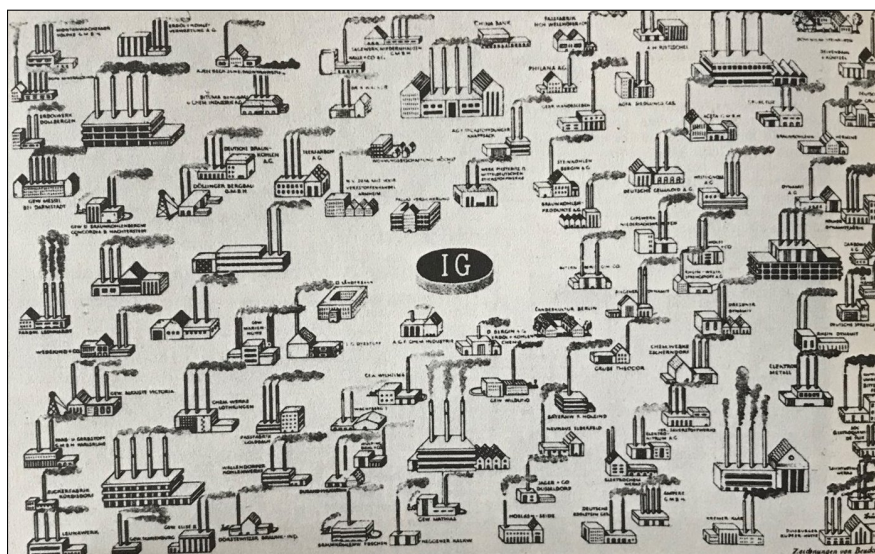
tralization: separate technical and product committees, sales groups, and three operating divisions (Figure B.9).

The combine then produced another wave of innovations. Through the late 1920s and 1930s, IG Farben developed synthetic rubber (Buna), the sulfonamides, polyurethanes, the synthetic fiber Perlon, and single-film color photography (Agfacolor). It also industrialized coal-hydrogenation fuels and a range of commodity plastics (Abelshauser et al., 2004). These products were developed within the pooled research and committee structure inherited from the *Dreibund*. Synthetic rubber, fuels, and fibers were import-substituting technologies with civilian and military uses.

B.2.2 Postwar Decartelization

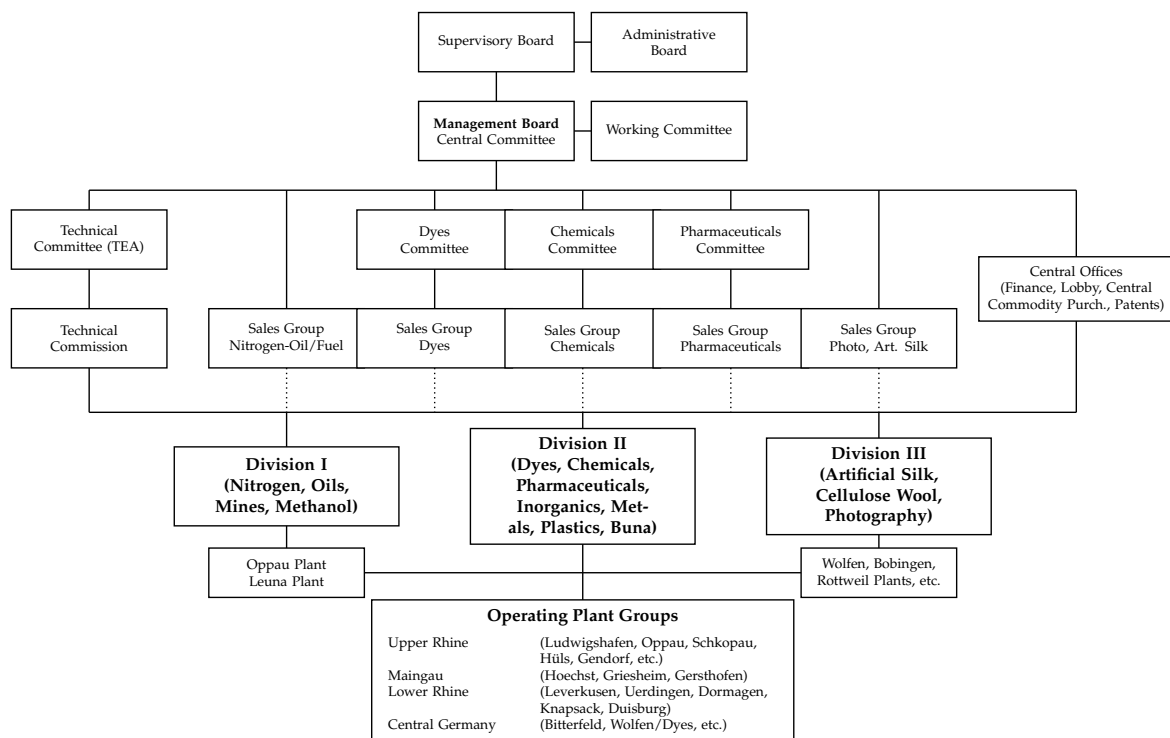
The centrality of the chemical cartel to two wartime mobilizations shaped the Allied response after the Second World War. Figure B.10 reproduces two primary sources: a *New York Times* front page from September 1944 documenting the emerging Allied consensus on decartelization, and a photograph of the defendants at the 1947–1948 IG Farben trial before the U.S. Military Tribunal at Nuremberg. The U.S. Decartelization Branch, created under military government, targeted the

Figure B.8: IG Farben Merger, 1925



Note. Organizational diagram of the 1925 IG Farben merger.

Figure B.9: Organizational Structure of IG Farben



Note. Organizational structure of IG Farben after the 1925 merger: the supervisory and management boards, technical and product committees, sales groups, and three operating divisions. Source: organizational chart after Feldenkirchen (1987).

chemical cartel system as a primary object of dismantlement (Crane, 2023). The target was the same organizational infrastructure documented in this appendix.

Figure B.10: Allied Decartelization and the IG Farben Trial

A: *New York Times*, 8 September 1944



B: IG Farben Trial, Nuremberg, 1947



Note. Panel A reproduces the *New York Times* front-page article of 8 September 1944. Panel B shows the defendants at the 1947–1948 IG Farben trial at Nuremberg.

B.2.3 Electrical Industry

Telefunken and Wireless At the turn of the century, AEG's Slaby–Arco system and Siemens & Halske's Braun system competed under overlapping wireless patents. The dispute weakened both systems in foreign markets and exemplified the duplicative competition discussed in Section 2.2. In 1903, the firms combined their wireless operations in Telefunken, with the state facilitating the venture because naval and colonial communications were strategic priorities (Chandler, 1990).

Coordination operated on two additional margins. First, the patents of the two systems were pooled into the venture rather than litigated. Second, an international agreement around 1912 divided world markets with the competing Marconi system, while a jointly owned operating company coordinated maritime wireless stations from 1911. With patents and revenue pooled, the venture could fund sustained development: it scaled the high-power transmitting station at Nauen and developed long-range continuous-wave transmission instead of spending resources on litigation.

High-Speed Electric Traction The German electrical industry centered on AEG and Siemens & Halske, which coordinated product by product through sales agreements in mature lines and joint ventures in newer, capital-intensive lines (Chandler, 1990). High-speed traction was one such venture. In 1899, AEG, Siemens & Halske, Deutsche Bank, Krupp, Borsig, and Van der Zypen & Charlier formed the Studiengesellschaft für Elektrische Schnellbahnen to test high-speed electric rail. The Prussian state provided the Marienfelde–Zossen military railway as a test track.

The test line, the high-tension three-phase power feed, and the experimental railcars were complementary sunk investments. No single firm was likely to finance the full system alone. The research company pooled capital and risk, and AEG and Siemens & Halske each equipped a competing railcar. In 1903, the AEG car reached 210.2 kilometers per hour, then the fastest speed recorded by a crewed vehicle. The experiment established three-phase high-speed electric traction, an ancestor of high-speed electric railways. The electric-rail speed record stood until 1954.

Amplifier Tubes and the Lieben Consortium In 1912, AEG, Siemens & Halske, Felten & Guilleaume, and Telefunken formed a consortium to commercialize Robert von Lieben's amplifier tube. They pooled patents and jointly financed development, extending the AEG–Siemens coordination already embodied in Telefunken (Chandler, 1990). The consortium converted a fragile laboratory valve into a manufacturable amplifier for telephone repeaters and radio. Vacuum-tube amplification became essential to long-distance telephony and radio and was later replaced by transistor amplification.

Electric Lamps Incandescent lamps show the limits of coordination. The cartel consolidated mature production but did not generate the key filament innovations. Osmium, tantalum, and tungsten filaments that displaced carbon were developed by individual inventors or firms between 1898 and 1906. General Electric in the United States developed the ductile tungsten filament that remains the basis of incandescent and halogen lamps (Chandler, 1990). The German joint sales office formed in 1903 organized the carbon-filament trade just as metal filaments made it obsolete. In 1920, AEG, Siemens & Halske, and Auergesellschaft combined their lamp operations in OSRAM. That consolidation rationalized mature manufacturing; it did not produce the underlying inventions.

Coordination also harmed consumers. In 1924, the major producers, including OSRAM, formed the international Phoebus agreement. The agreement fixed the rated life of a standard lamp at 1,000 hours, below the life the technology then allowed, and fined members whose lamps lasted longer (Chandler, 1990). Shorter service life increased replacement demand. The welfare loss is bounded because a hotter filament produces more light per watt, so shorter life is partly a trade-off against efficiency rather than pure waste. The cartel shortened product life without changing the underlying technology. The lamp case therefore contrasts firm-level innovation before production pooling with later coordination that reduced product durability.

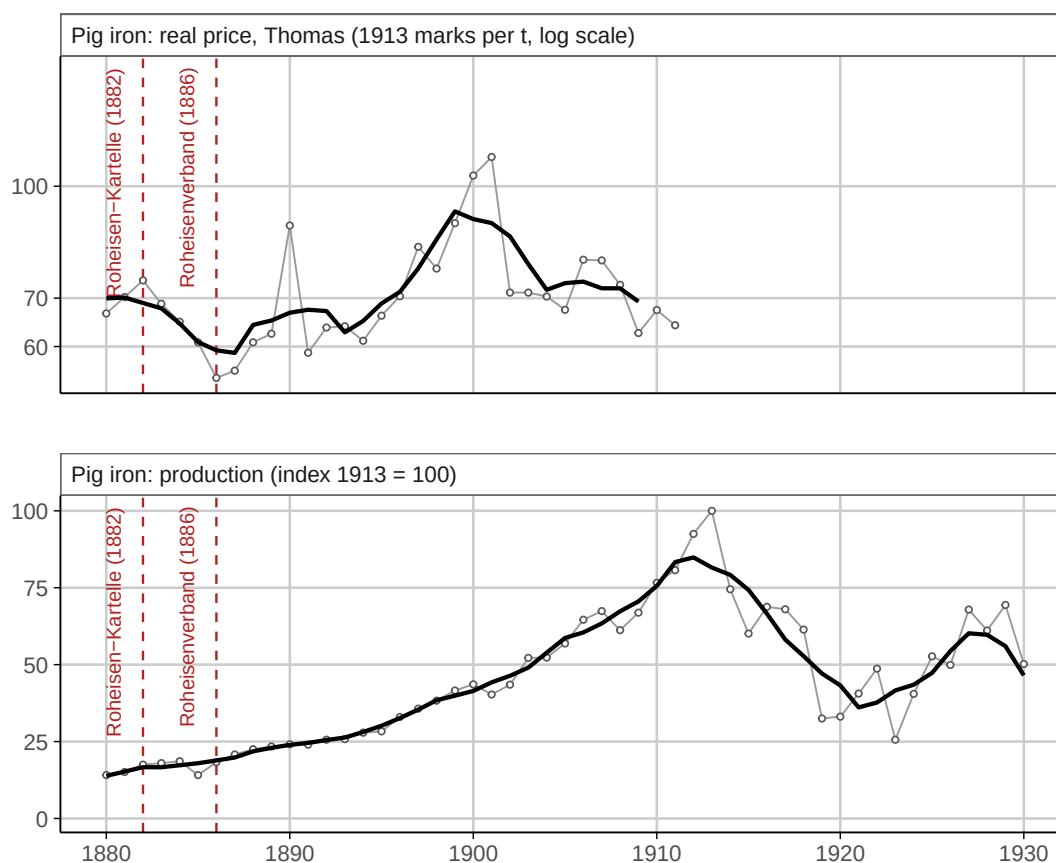
B.2.4 Iron and Steel

Heavy industry was organized under the Steel Works Association of 1904 and product syndicates that operated export-rebate systems. Figure B.11 reports pig-iron prices and output.

Wire rod and wire nails. By the First World War, Germany had overtaken Britain as the largest steel exporter and sold semifinished steel and wire in Britain below British prices (Webb, 1980). A two-tier price structure supported this strategy: high domestic prices subsidized lower export prices. In the second half of 1900, the wire-nail association charged German buyers 25 marks and foreign buyers 14 marks per Doppelzentner, selling profitably at home and at a loss abroad (Morgenroth, 1907). Table B.1 shows the annual domestic-export wedge; export prices fell below domestic prices during the most active years of the syndicate.

The export strategy rested partly on an efficiency advantage. In 1907–1909, total factor productivity in German steelmaking was about 10 percent above the British level (Webb, 1980). Investment, not collusion alone, is the relevant mechanism: stable domestic prices helped finance large, vertically integrated plants and reduced the risk of capital-intensive investment (Webb, 1982, p. 221). Because tariffs, cartels, and scale economies operated jointly, the cartel's separate contribution cannot be identified. Table B.1 documents discriminatory pricing; the productivity comparison shows that the export strategy also rested on lower production costs.

Figure B.11: Pig Iron: Price and Production, 1880–1930



Note. Quoted price of Thomas pig iron in marks per ton, ex works, deflated to constant 1913 marks by the all-goods wholesale price index, on a log scale. The quoted series ends in 1911. Production is pig-iron output, indexed to 1913 = 100, on a linear scale, through 1930. The heavy line is a five-year moving average. Dashed lines mark cartelization dates. Source: prices from Müssig (1919, p. 203); deflator from Jacobs and Richter (1935); production from Hoffmann (1965, pp. 352–354).

Table B.1: Wire Nails: Domestic and Export Prices

Year	Domestic	Export	Export – Domestic
1895	12.25	15.00	+2.75
1896	13.13	16.00	+2.87
1900	25.13	21.00	–4.13
1901	17.75	16.00	–1.75
1902	14.75	16.50	+1.75

Note. Prices are marks per Doppelzentner (100 kilograms) of wire nails. The final column is the export price less the domestic price; negative values indicate an export price below the domestic price. Source: Morgenroth (1907).

B.2.5 Coal and Potash

Coal and potash were homogeneous extractive goods, each organized by a large syndicate. In both cases, quotas and closures shifted output toward larger producers. The available evidence

does not isolate the causal effect of syndication on unit cost.

Coal. The Rhenish–Westphalian Coal Syndicate, founded in 1893, absorbed the Westphalian coke syndicate and the lignite-briquette association; by 1913, it controlled most Ruhr coal output (Webb, 1982). Tradable production quotas allowed efficient mines to acquire and retire the quotas of weaker competitors, shifting output to lower-cost pits (Levy, 1935). The share of collieries producing no more than 500,000 tons a year fell from 72.8 percent in 1900 to 23.8 percent in 1928, and the number of operating collieries fell from 350 in 1913 to 294 in 1928. The share of machine-cut coal rose from 59.4 percent in 1925 to 77.7 percent in 1928 (Levy, 1935). Byproduct coke ovens also spread during this period, replacing beehive ovens and recovering ammonia, tar, and benzol from coking. The real price of Ruhr coal rose by about half across the cartelization wave from the sales associations of 1888 to the syndicate of 1893 and stayed near that level through 1913. Hard-coal production quadrupled between 1880 and 1913 (Figure B.12). This reallocation mechanism should not be read as a claim that cartelization caused productivity growth in the industry.⁵

Potash. Germany held a natural monopoly in potash before 1918. The industry operated under a potash syndicate and, after the 1910 potash law, a compulsory syndicate. State enforcement and cartel quotas jointly rationalized capacity. Large groups acquired smaller works mainly to obtain their quotas and then closed the acquired capacity; the 1910 compulsory-syndicate law and the 1921 closure ordinance made this process binding (Levy, 1935). Output shifted toward larger, modernized mines. Sales of pure potash per mine rose from 59,000 Doppelzentner in 1921 to 237,000 in 1928, above the 1912 level of 100,000. Power and fuel costs per 100 kilograms fell by about 50 percent between 1924 and 1930 (Levy, 1935).

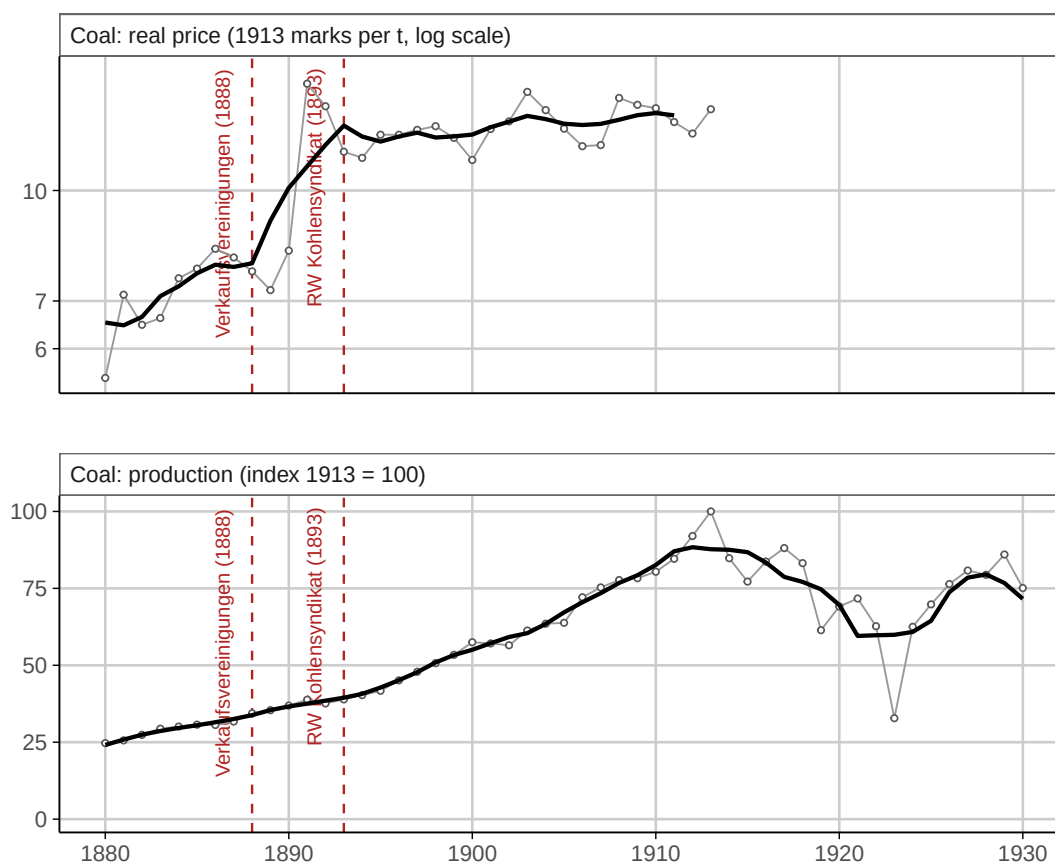
B.2.6 Patterns of Innovation

The case studies are consistent with the quantitative evidence in the main text along several margins. First, the member-firm gain in Section 5.1 is consistent with the observable trajectories of the cartel members studied here in chemicals, electrical engineering, and steel. Second, the investment-based mechanism in Section 5.3 is visible in the allocation of retained earnings to research: catalyst trials and the high-pressure program in chemicals, pooled patents in wireless, and the concentration of output and joint adoption of byproduct coking in coal. Third, the Coasean mitigation in Section 6.1 corresponds to the explicit cross-sector contracts: the export-rebate arrangements in steel and the long-term coal supply contracts in chemicals. These arrangements internalized upstream and downstream externalities. Fourth, the war-economy embedding in Section 5.4 appears in the redirection of synthetic-nitrogen infrastructure to explosives (Appendix B.2.1, Figure B.3) and in the postwar Allied effort to dismantle the same organizational infrastructure (Appendix B.2.2, Figure B.10). These patterns are also consistent with the larger member-firm gains in dual-use industries reported in Section 5.3.

The pattern of innovation across these cases reflects substitution technologies that reduced dependence on imported goods and raw materials. Examples include synthetic fertilizers, synthetic rubber, synthetic fuels, synthetic fibers, synthetic camphor, synthetic dyes, and the magnesium alloy Elektron. These innovations carried high strategic value, with dual-use capabilities for both civilian and wartime production. The Haber–Bosch process for ammonia substituted for Chilean

⁵The firm-level efficiency effect of coal cartelization is contested. Burhop and Lübbes (2009) finds no pre-1913 cartel effect and attributes measured gains to managerial incentives. Studies of the interwar period attribute most productivity growth to mechanization within surviving mines rather than to closures. The narrower claim is that cartel-administered quotas shifted capacity toward lower-cost producers in hard coal and coke.

Figure B.12: Coal: Price and Production, 1880–1930



Note. Quoted price of best-blended Fettkohle with 50 percent lumps, ex Rhenish–Westphalian colliery, in marks per ton and deflated to constant 1913 marks by the all-goods wholesale price index, on a log scale. The price series ends in 1913. Hard-coal output is indexed to 1913 = 100 on a linear scale and extends through 1930. The heavy line is a five-year moving average; dashed lines mark cartelization dates. Sources: prices from Müssig (1919, p. 138); deflator from Jacobs and Richter (1935); production from Hoffmann (1965, pp. 338–343).

nitrate and reorganized agriculture and explosives production around domestically controlled nitrogen, reducing the strategic risk from blockade; synthetic rubber answered the same imperative to secure tire supplies against trade disruption. Many technologies also used economies of scope, recycling byproducts across sectors: the production of magnesium generated chlorine as a waste output, and through coordination that chlorine was used to manufacture thermoplastics, a domestic substitute for imported materials. As they scaled, these technologies did not merely replace natural inputs at the margin; they altered relative prices and the terms of trade, contributing to the collapse of world markets for natural indigo and nitrate.

The cases therefore highlight a scope condition of the main results. Cartels were not innovative because market power is intrinsically productive. They were innovative when the cartel contract solved a specific organizational problem: financing indivisible investment, sharing technological risk, coordinating complementary inputs, or reallocating production toward lower-cost capacity. The welfare-relevant object is therefore not cartelization itself but the use of cartel rents. The same institution could finance synthetic nitrogen or shorten the life of a light bulb. The factors that disciplined firms included both market forces, such as product-market competition in tradable goods, and nonmarket incentives, such as strategic competition among states.

C Model

C.1 Proofs

Proof of Proposition 1. Period 1. Q_1 solves $V_Q + \mu V_{QQ}Q = C_{1,Q}$; implicit differentiation gives $Q_{1,\mu} = -V_{QQ}Q_1/F_{1,Q} < 0$, with $F_{1,Q} < 0$ the stability condition, so $Q_1(\mu) < Q_1(0)$ for $\mu > 0$. Since $P_1 = V_Q(Q_1)$ and $V_{QQ} < 0$, $P_1(\mu) > P_1(0)$. Period 2. Q_2 solves $F_2(Q, \mu, I) \equiv V_Q(Q) + \mu V_{QQ}(Q)Q - C_{2,Q}(Q, I) = 0$. Along $I = I(\mu) = B + \pi_1(\mu)$ (Assumption 2), $dQ_2/d\mu = -(F_{2,\mu} + F_{2,I}I_\mu)/F_{2,Q} = Q_{2,\mu} + Q_{2,I}\pi_{1,\mu}$. Writing $\bar{Q}_2 \equiv Q_2(0, I(0))$ and taking F_2 to single-cross in Q (the global form of the stability condition), $Q_2(\mu, I(\mu)) > \bar{Q}_2$ iff $F_2(\bar{Q}_2, \mu, I(\mu)) > 0$; with $V_Q(\bar{Q}_2) = C_{2,Q}(\bar{Q}_2, I(0))$ at competition this is

$$\underbrace{C_{2,Q}(\bar{Q}_2, I(0)) - C_{2,Q}(\bar{Q}_2, I(\mu))}_{\text{cost reduction}} > \underbrace{-\mu V_{QQ}(\bar{Q}_2) \bar{Q}_2}_{\text{market power wedge}}, \quad (14)$$

the cost reduction exceeding the market power wedge at $\bar{Q}_2$. Finally $P_2 = V_Q(Q_2)$ with $V_{QQ} < 0$ gives $P_2(\mu) < P_2(0)$ iff $Q_2(\mu, I(\mu)) > \bar{Q}_2$. $\square$

Proof of Proposition 2. Facing the tariff the buyer sets $V_Q(Q) = w$; with $w = C_{2,Q}(Q^E(I(\mu)), I(\mu))$ this yields $Q^E(I(\mu))$ by the definition of Q^E , at which price equals marginal cost, and the fee transfers surplus, surplus-neutral under quasilinearity. The finance cap $B + \pi_1(\mu)$ is unchanged, since period-1 output and profit are unchanged. Under efficient trade the firm's return to investment is $S^E = -C_{2,I}(Q^E, I)$; since $Q^E = Q_2(0, I) \geq Q_2(\mu, I)$ and $C_{2,QI} < 0$, $S^E \geq -C_{2,I}(Q_2, I) \geq \pi_{2,I}$, so with $\delta\pi_{2,I}(\mu, I(\mu)) \geq 1$ under the binding borrowing constraint (Assumption 2), $\delta S^E(I(\mu)) \geq \delta\pi_{2,I} \geq 1$; the firm still invests up to the cap, $I(\mu) = B + \pi_1(\mu)$. $\square$

Proof of Proposition 3. Differentiating $\pi_2 = P(Q_2)Q_2 - C_2$ in I and using $P = V_Q$, $\pi_{2,I} = -C_{2,I} + (V_Q + V_{QQ}Q_2 - C_{2,Q})Q_{2,I}$. The conduct equation gives $V_Q - C_{2,Q} = -\mu V_{QQ}Q_2$, so $\pi_{2,I} = -C_{2,I} + (1 - \mu)V_{QQ}Q_2 Q_{2,I}$. Subtracting from (3), the cost saving cancels and $S - \pi_{2,I} = -V_{QQ}Q_2 Q_{2,I}$, positive since $V_{QQ} < 0$, $Q_2 > 0$, $Q_{2,I} > 0$. With $MR_2 = V_Q + V_{QQ}Q_2$ and $P_2 = V_Q$, $P_2 - MR_2 = -V_{QQ}Q_2$. $\square$

Proof of Proposition 4. Differentiate (5), with $Q_1 = Q_1(\mu)$, $Q_2 = Q_2(\mu, I)$, $I = I(\mu)$, and total period-2 output response $Q_{2,\mu} + Q_{2,I}I_\mu$:

$$W_\mu = (V_Q(Q_1) - C_{1,Q})Q_{1,\mu} - I_\mu + \beta[(V_Q(Q_2) - C_{2,Q})(Q_{2,\mu} + Q_{2,I}I_\mu) - C_{2,I}I_\mu].$$

The conduct equation gives $V_Q - C_{2,Q} = -\mu V_{QQ}Q_2$, so the price-marginal-cost terms on the direct market power responses are $-L_1$ and $-\beta L_2$, while the I_μ terms collect into $\beta[(-\mu V_{QQ}Q_2)Q_{2,I} - C_{2,I}]I_\mu = \beta S I_\mu$ by (3). Hence $W_\mu = [-1 + \beta S]I_\mu - (L_1 + \beta L_2) = G - L$. $\square$

Proof of Proposition 5. At $\mu = 0$ the markup $-\mu V_{QQ}Q_2$ is zero, so $L(0) = 0$ and the output-expansion term of $S(0, I(0))$ vanishes. Then $W_\mu(0) = G(0) = [-1 + \beta S(0, I(0))]I_\mu(0)$ with $I_\mu(0) = \pi_{1,\mu}(0) > 0$ under Assumption 2, positive iff $\beta S(0, I(0)) > 1$. $\square$

Proof of Corollary 3. At an interior μ^W , $W_\mu(\mu^W) = 0$ with $W_{\mu\mu}(\mu^W) < 0$ by strict descent. Continuity with $W_\mu(0) > 0$ and $W_\mu(1) < 0$ gives a zero in $(0, 1)$; strict monotonicity makes it unique, and $G(\mu^W) = L(\mu^W)$ is $W_\mu(\mu^W) = 0$. $\square$

Proof of Proposition 6. The optimum solves $W_\mu(\mu^W) = 0$; with $W_{\mu\mu}(\mu^W) < 0$ the implicit function theorem gives $d\mu^W/dx = -W_{\mu x}/W_{\mu\mu}$, so $\text{sgn}(d\mu^W/dx) = \text{sgn } W_{\mu x}$. In the borrowing-constrained

regime $I_B = 1$ and $I_{\mu B} = 0$, so $W_{\mu B} = \beta[S_I I_\mu - L_{2,I}] < 0$ under the stated signs. For the discount factor, $W_{\mu\beta} = S I_\mu - L_2$; at the optimum $[-1 + \beta S] I_\mu = L_1 + \beta L_2$, so $\beta(S I_\mu - L_2) = L_1 + I_\mu > 0$. $\square$

Proof of Corollary 1. By Proposition 2, investment stays at $I(\mu) = B + \pi_1(\mu)$ and only period-2 trade changes. Period-2 surplus rises by $\Delta(\mu, I(\mu)) \geq 0$ because Q^E maximizes period-2 surplus, so $W^E(\mu) = W(\mu) + \beta \Delta(\mu, I(\mu))$, with $\Delta(0, I) = 0$ since $Q_2(0, I) = Q^E(I)$. Differentiating $W^E(\mu) = V(Q_1) - C_1(Q_1) - I(\mu) + \beta[V(Q^E(I(\mu))) - C_2(Q^E(I(\mu)), I(\mu))]$, the period-1 term is $-L_1$ by the conduct equation and the period-2 term is $\beta S^E(I(\mu)) I_\mu$ by the envelope theorem at Q^E , so $W_\mu^E = [-1 + \beta S^E(I(\mu))] I_\mu - L_1(\mu)$. $\square$

C.2 Functional Forms

The preceding analysis holds for any demand and cost satisfying the sign assumptions. Now assume isoelastic,

$$P(Q) = \psi Q^{-1/\varepsilon}, \quad C_1(Q) = \frac{\eta}{\eta+1} Q^{(\eta+1)/\eta}, \quad C_2(Q, I) = (1+I)^{-\gamma} C_1(Q), \quad (15)$$

with demand elasticity $\varepsilon > 1$, supply elasticity $\eta > 0$, and cost-reduction elasticity $\gamma > 0$. The conduct equation reduces to a constant Lerner index, $(P - C_{t,Q})/P = \mu/\varepsilon$. Define

$$\sigma \equiv \frac{\eta\varepsilon}{\eta+\varepsilon}, \quad \rho \equiv \frac{\eta(\varepsilon-1)}{\eta+\varepsilon}, \quad \chi \equiv \frac{\eta}{\eta+1}, \quad \Psi \equiv \psi^{1+\rho},$$

the output response to a demand or cost shift (σ), the elasticity of revenue and operating profit (ρ), the competitive cost share of revenue (χ), and the revenue scale (Ψ). Quantities are

$$Q_1(\mu) = [\psi(1 - \mu/\varepsilon)]^\sigma, \quad Q_2(\mu, I) = [\psi(1 - \mu/\varepsilon)(1+I)^\gamma]^\sigma. \quad (16)$$

Operating profit is revenue net of cost,

$$\pi_1(\mu) = R_1[1 - \chi(1 - \mu/\varepsilon)], \quad \pi_2(\mu, I) = \pi_1(\mu)(1+I)^{\gamma\rho}. \quad (17)$$

Revenue is $R_t = \Psi(1 - \mu/\varepsilon)^\rho(1+I)^{\gamma\rho}$, with $I = 0$ in period 1. $\pi_1(0) = \Psi/(\eta+1)$ and $\pi_{1,\mu} = \sigma(1 - \mu)\varepsilon^{-2}\Psi(1 - \mu/\varepsilon)^{\rho-1}$, positive for $\mu < 1$ and zero at $\mu = 1$. Both cost and downstream surplus are a fraction of revenue, $C_t = \chi(1 - \mu/\varepsilon)R_t$ and $DS_t = R_t/(\varepsilon - 1)$. Assumption 4 holds here at competition: from $\pi_{2,I} = \gamma\rho\pi_1(\mu)(1+I)^{\gamma\rho-1}$, its dependence on market power is $g(\mu) = (1 - \mu/\varepsilon)^\rho[1 - \chi(1 - \mu/\varepsilon)]$, and $g'(0) \propto \sigma - \rho > 0$ since $\sigma = \rho\varepsilon/(\varepsilon - 1) > \rho$, so $\pi_{2,\mu I}(0) > 0$. Since $g'(\mu) = \pi_{1,\mu}/\Psi \propto (1 - \mu) \geq 0$ on $[0, 1]$, vanishing only at $\mu = 1$, the condition holds throughout under these functional forms.

The marginal social value of investment is

$$S(\mu, I) = \gamma\Psi(1 - \mu/\varepsilon)^\rho(1+I)^{\gamma\rho-1}[\chi(1 - \mu/\varepsilon) + \mu\sigma/\varepsilon], \quad (18)$$

the bracket adding the cost saving on existing output, $\chi(1 - \mu/\varepsilon)$, to the surplus value of the output investment induces, $\mu\sigma/\varepsilon$. The private return $\pi_{2,I} = \gamma\rho\pi_1(1+I)^{\gamma\rho-1}$ captures the cost saving and upstream's own marginal revenue but not the downstream surplus on the induced output. So the investment wedge of Proposition 3 is

$$S(\mu, I) - \pi_{2,I}(\mu, I) = \frac{\sigma}{\varepsilon} \frac{\gamma R_2}{1+I} > 0, \quad (19)$$

a fraction $1/\varepsilon$ of the value of the investment-induced output, $P_2 Q_{2,I} = \sigma \gamma R_2 / (1 + I)$.

Assumption 3 (Diminishing returns to investment). *Period-2 profit is concave in investment, $\pi_{2,II} < 0$ (Section 3.1). This implies*

$$\gamma \rho = \frac{\gamma \eta (\varepsilon - 1)}{\eta + \varepsilon} < 1. \quad (20)$$

This elasticity of profit to investment is the product of how strongly investment lowers marginal cost (γ) and how strongly a lower cost raises profit (ρ).

Desired investment is

$$I^p(\mu; r) = \max \left\{ 0, \left[\frac{\gamma \rho \pi_1(\mu)}{1+r} \right]^{1/(1-\gamma \rho)} - 1 \right\}. \quad (21)$$

I^p is interior only where the marginal return covers the cost of funds at $I = 0$, $\gamma \rho \pi_1(\mu) > 1 + r$, and zero otherwise. Along the constrained path $I(\mu) = B + \pi_1(\mu)$, the marginal social value falls, $d \log S / d\mu \leq 0$, through two channels: market power contracts the surplus base $(1 - \mu/\varepsilon)^\rho [\chi(1 - \mu/\varepsilon) + \mu\sigma/\varepsilon]$ of (18), and investment has diminishing returns, $\gamma \rho - 1 < 0$ (Assumption 3).

Output and prices. Period-2 output rises above its competitive level, and price falls below, exactly when the cost-reduction factor exceeds the gross markup,

$$\left(\frac{1 + I(\mu)}{1 + I(0)} \right)^\gamma > \frac{1}{1 - \mu/\varepsilon}. \quad (22)$$

Marginal surplus at competition. Where the borrowing constraint binds, $I(0) = B + \pi_1(0)$, the condition $\beta S(0, I(0)) > 1$ of Proposition 5 becomes

$$\beta S(0, I(0)) = \beta \gamma \chi \Psi \left(1 + B + \frac{\Psi}{\eta+1} \right)^{\gamma \rho - 1} > 1. \quad (23)$$

This discounted social return, earned on the investment that a marginal increase in market power finances starting from the competitive baseline, rises in the discount factor β , the cost-reduction elasticity γ , the cost share χ , and the demand scale Ψ , and falls in external finance B .

Comparative statics. For Proposition 6,

$$W_{\mu B} = \frac{\beta}{1 + I} [(\gamma \rho - 1) S I_\mu - \gamma \rho L_2] < 0, \quad W_{\mu \beta} = S I_\mu - L_2,$$

so $d\mu^W/dB < 0$, and $d\mu^W/d\beta > 0$ since $W_{\mu \beta} > 0$ at μ^W .

Ex post contracting. Under the downstream-buyer contracting benchmark of Section 3.3, the efficient output is $Q^E(I) = [\psi(1 + I)^\gamma]^\sigma = Q_2(0, I)$ and the linear-pricing output is $Q_2(\mu, I) = Q^E(I)(1 - \mu/\varepsilon)^\sigma$. The social return to investment at the efficient output is its competitive value,

$$S^E(I) = S(0, I) = \gamma \chi \Psi (1 + I)^{\gamma \rho - 1}, \quad (24)$$

independent of μ : making period 2 efficient sets the return to the cost saving alone. Under a binding borrowing constraint the fixed fee is a transfer and the split of surplus does not affect the

total, since investment is pinned at $B + \pi_1(\mu)$. The recovered surplus is the period-2 loss from market power under linear pricing,

$$\Delta(\mu, I) = \Psi(1 + I)^{\gamma\rho} D(\mu) \geq 0, \quad D(\mu) \equiv \frac{\varepsilon}{\varepsilon-1} (1 - m^\rho) - \chi (1 - m^{\rho+1}), \quad m \equiv 1 - \frac{\mu}{\varepsilon}, \quad (25)$$

which scales with revenue, so $\Delta_I = \gamma\rho \Delta / (1 + I) \geq 0$: the recovered surplus is investment-complementary here as a property of the functional forms.⁶ Then $W_\mu^E = [-1 + \beta S(0, I)] \pi_{1,\mu} - L_1$ (with $I_\mu = \pi_{1,\mu}$ under a binding borrowing constraint), the condition for total surplus to rise off competition is again (23), and

$$W_{\mu B}^E = \frac{\beta(\gamma\rho - 1)}{1 + I} S(0, I) \pi_{1,\mu} < 0, \quad W_{\mu\beta}^E = S(0, I) \pi_{1,\mu} > 0,$$

the first negative because $\gamma\rho < 1$ (Assumption 3), so $S_I^E < 0$ with no further condition.

C.3 Calibration

Table C.1 lists the parameter values used to draw the model figures.

Table C.1: Calibration and Implied Conditions

Object	Value	Role
<i>Panel A: Parameters</i>		
ψ	6	Demand level
ε	3	Demand elasticity
η	10	Cost convexity
γ	0.55	Cost-reduction elasticity
N	10	Sellers per sector
B	0.1	External finance, constrained sector
$\bar{I}$	3.5	Full project size
r	0.03	Firm discount rate, $\delta = 1/(1 + r)$
β	0.95	Social discount factor
κ	0.49	Enforceability after the shock
<i>Panel B: Implied conduct and regime</i>		
$\mu^C(0)$	0.02	Constrained conduct without a contract, below Cournot ($1/N$)
$\mu^C(\kappa)$	0.50	Constrained period-1 conduct
$\mu^U(\kappa)$	0.54	Period-2 conduct; unconstrained conduct in both periods
$B + \pi_1(\mu^U(\kappa))$	2.63 ($\leq \bar{I}$)	The sector stays borrowing-constrained
$I(\kappa)/I(0)$	1.85	Investment response

Note. Calibration values for Figure 3 and Appendix Figure A.3. The unconstrained sector differs only in holding the full project, $I = \bar{I}$, throughout. Both figures raise γ to 0.85 for visual legibility, and κ is set where period-2 output of the constrained sector then rises most. The values in Panel B do not depend on γ .

⁶Positivity is explicit: $D(0) = 0$ and $D(\mu) > 0$ for $\mu > 0$, since with $F(m) \equiv m^\rho (\frac{\varepsilon}{\varepsilon-1} - \chi m)$ one has $D = F(1) - F(m)$ and $F'(m) = \sigma(1 - m)m^{\rho-1} \geq 0$ by the identity $\rho\varepsilon/(\varepsilon - 1) = \chi(1 + \rho) = \sigma$, so F rises on $m \leq 1$. The same derivative gives $\Delta_\mu = \Psi(1 + I)^{\gamma\rho} \sigma \mu \varepsilon^{-2} m^{\rho-1} = L_2$, the period-2 static loss.

C.4 Conduct as an Oligopoly Outcome

The conduct equation admits a simple oligopoly foundation. This appendix gives one, a static N -seller oligopoly, and shows that μ blends the number of sellers with the intensity with which they internalize each other's profit.

Oligopoly. Let N symmetric sellers each produce q_i . In period t the per-firm cost is $c_t(q_i, I)$, with investment I entering period 2, so sector output is $Q = \sum_i q_i$, sector cost is $N c_t(Q/N, I)$, and sector marginal cost is $C_{t,Q} = c_{t,q}(Q/N, I)$ at the symmetric allocation. Suppressing the period and investment arguments, each seller places weight $\kappa \in [0, 1]$ on joint profit and $1 - \kappa$ on its own,

$$\max_{q_i} (1 - \kappa) \pi_i + \kappa \sum_j \pi_j, \quad \pi_k = P(Q) q_k - c(q_k).$$

The first-order condition in q_i is $P - c'(q_i) + P'[(1 - \kappa)q_i + \kappa Q] = 0$; at the symmetric equilibrium $q_i = Q/N$ it becomes

$$P(Q) + \left[\frac{1 - \kappa}{N} + \kappa \right] P'(Q) Q = c'(Q/N),$$

which is the conduct equation with $V_Q = P$, $V_{QQ} = P'$, and $C_{t,Q} = c'(Q/N)$, at conduct

$$\mu = \mu^U(\kappa) \equiv \frac{1}{N} + \kappa \left(1 - \frac{1}{N} \right). \quad (26)$$

The weight κ is the share of the harm to rivals that each seller internalizes at the margin. A court that enforces fines for output above quota up to a share κ of that harm sustains the same conduct in an unconstrained sector. In a borrowing-constrained sector, overproduction also lowers rivals' earnings and therefore their investment, which raises the gain from deviating, so the highest sustainable conduct falls to $\mu^C(\kappa) \leq \mu^U(\kappa)$ whenever rival investment lowers a seller's profit.

Interpretation. Conduct combines market structure and profit internalization. With pure quantity competition ($\kappa = 0$), conduct is $\mu = 1/N$; with full profit internalization ($\kappa = 1$), conduct is joint profit maximization, $\mu = 1$, for any N . The competitive benchmark $\mu = 0$ is the large- N limit with no internalization. In the large- N benchmark used in the main text, μ can be read directly as the profit-internalization parameter: $\mu = 0$ is the absence of coordination, and any $\mu > 0$ is coordinated conduct.

The parameter κ can be generated by enforceable agreement, by cross-ownership, or by overlapping control rights. Thus the conduct index μ should be understood as the reduced-form outcome of a commitment or control structure rather than as a spot pricing choice.

Common conduct across periods. We take conduct to be common across periods because the commitment or control structure that generates κ is durable. In a two-period model, common conduct is not sustained by repeated-game punishments. Instead, it is sustained by a two-period commitment to the conduct regime, either through state enforcement of private commitments or through persistent ownership and control rights. When that structure survives the period-1 investment and is not renegotiated, (26) fixes the same μ in both periods.

C.5 Appropriability

This appendix formalizes the appropriability channel flagged in Remark 1: outside the maintained binding borrowing constraint, period-2 market power can raise total surplus in its own right, by giving upstream the incentive to invest rather than the funds to do so.

Assumption 4 (Market power–investment complementarity). *At competition, period-2 market power raises upstream’s private return to investment, $\pi_{2,\mu I}(0) \geq 0$, equivalently $I_\mu^p(0) \geq 0$ given $\pi_{2,II} < 0$. Upstream never fully appropriates the social return to investment ($\pi_{2,I} < S$, Proposition 3), so a higher period-2 markup can let it capture more of the surplus on the output that investment adds, which raises the private return; the same markup also contracts the base to which the cost saving applies, which lowers it. The net sign is a restriction on demand and cost curvature, not implied by the maintained assumptions.*

Lemma 1 (Appropriability of period-2 market power). *Let market power be set independently across periods, $\mu = (\mu_1, \mu_2)$, so $Q_1 = Q_1(\mu_1)$, $Q_2 = Q_2(\mu_2, I)$, and $I \leq B + \pi_1(\mu_1)$. Holding μ_1 fixed,*

$$W_{\mu_2} = [-1 + \beta S(\mu_2, I)] I_{\mu_2} - \beta L_2(\mu_2), \quad L_2(0) = 0, \quad L_2(\mu_2) > 0 \text{ for } \mu_2 > 0. \quad (27)$$

Outside the maintained borrowing-constrained regime, separating the periods need not make period-2 market power redundant. When investment is set on upstream’s own margin (unconstrained, $I = I^p(\mu_2; r)$, absolutely continuous in μ_2) and Assumption 4 holds, period-2 market power raises the incentive to invest. Writing $G_2(s) \equiv [-1 + \beta S(s, I^p(s))] I_s^p(s)$,

$$W(\mu_2) - W(0) = \int_0^{\mu_2} [G_2(s) - \beta L_2(s)] ds, \quad (28)$$

so competition in period 2 is not surplus-maximizing, $\mu_2^W > 0$, under either of two conditions: at an interior margin $I^p(0) > 0$ with $I_\mu^p(0) > 0$, competition is not a local optimum iff $\beta S(0, I^p(0)) > 1$, the threshold of Proposition 5 with $I(0) = I^p(0; r)$; at the corner $I^p(0) = 0$, upstream invests nothing until μ_2 reaches the threshold $\underline{\mu}$ solving $\delta \pi_{2,I}(\underline{\mu}, 0) = 1$, so $G_2 = 0$ and competition is a local optimum on $[0, \underline{\mu})$, yet by (28) it is globally dominated once the investment that switches on beyond $\underline{\mu}$ outweighs the accumulated static loss, $\int_{\underline{\mu}}^{\hat{\mu}} G_2 > \beta \int_0^{\hat{\mu}} L_2$ for some $\hat{\mu} \in (0, 1]$. Under the maintained binding borrowing constraint (Assumption 2), by contrast, the financeable bound pins investment: $I = B + \pi_1(\mu_1)$ is independent of μ_2 , so $I_{\mu_2} = 0$, $W_{\mu_2} = -\beta L_2 < 0$ for $\mu_2 > 0$, and $\mu_2^W = 0$, with every gain from market power running through μ_1 . Beyond the financing channel carried by μ_1 , then, appropriability can give period-2 market power independent value once the sector is not borrowing-constrained.

D Data Processing

This appendix describes the sources and processing steps for the synthetic-nitrogen case study, geography and industry classifications, investor handbooks, cartel registry, court decisions, patent gazette, input–output table, industrial censuses, and war-economy records. Where available, we show a sample scan. Most historical records are primary sources that we digitize; the input–output table and several comparison series come from existing datasets. The final subsection compares extracted employment with an independently hand-digitized panel.

D.1 Case Study Data

The synthetic-nitrogen case study in Section 2.3 uses four series shown in Figure 2: financing, nitrogen patents, fixed-nitrogen prices, and natural and industrial fixed-nitrogen output. Appendix Figure B.7 separately reports indigo and aniline-oil prices.

D.1.1 Investment and Financing

We manually compile a database of the money flows into synthetic-nitrogen research and capacity, from the prewar arc-process and Haber research contracts through the Oppau and Leuna plants to the IG Farben investment programs. We deduplicate the flows across four narrative accounts of the German nitrogen industry and one corporate-finance summary, so that the summed series does not double-count. Each flow records its amount and currency, its type, the party that provided it, and whether coordinated cartel capital financed it. Table D.1 lists these flows; amounts are nominal, in millions of the stated currency, and the figure deflates each flow to constant 1913 marks with the German consumer price index, converting Reichsmark amounts at the 1924 redenomination. The cartel-financed flows comprise coordinated capital raises of the Dreibund (the 1905 BASF–Bayer–Agfa pool) and the IG, partner-guaranteed state loans, retained earnings, and IG-era internal investment. Years in which the database records no flow enter as zero, so the cumulative series of Panel A is flat across them.

Table D.1: Synthetic-Nitrogen Investment and Financing

Years	Item	Amount (millions)	Cur.	Type	Provider	Cartel
1907	Norsk Hydro/Rjukan + Auguste Victoria package	34.0	Mark	Equity	Dreibund	✓
1908	BASF bonds for Ludwigshafen plant/apparatus	7.0	Mark	Bond	BASF	
1910	BASF ammonia/nitrate pilot program	0.1	Mark	Investment	BASF	
1913–1914	Oppau enlargement (first HB plant)	41.8	Mark	Equity	Dreibund	✓
1914	Reich grant, Oppau nitrate-conversion plant	6.0	Mark	Subsidy	Reich	
1914	Reich loan, Oppau ammonia expansion	35.0	Mark	Loan	Reich	✓

continued on next page

Table D.1, continued

Years	Item	Amount (millions)	Cur.	Type	Provider	Cartel
1914	Reich subsidy to BASF (Haber-negotiated)	1.0	Mark	Subsidy	Reich	
1914–1915	BASF own funds, Oppau ammonia expansion	15.0	Mark	Retained Earnings	BASF	✓ [†]
1915	Reich subsidies, Agfa Greppin saltpeter plants	6.3	Mark	Subsidy	Reich	
1916	Reich subsidy, Leuna phase I	12.0	Mark	Subsidy	Reich	
1916	Reich loan, Leuna phase I	64.0	Mark	Loan	Reich	✓
1917	Reich share, nitrogen expansion (Oct 1917)	199.0	Mark	Loan	Reich	
1917	BASF own funds, nitrogen expansion (Oct 1917)	40.0	Mark	Retained Earnings	BASF	✓ [†]
1917	Expanded IG contribution, nitrogen expansion	162.0	Mark	Equity	IG	✓
1919	Erka long-term loan, Leuna phase III	232.0	Mark	Loan	Reich	
1925–1929	IG Farben investment, Leuna	256.0	RM	Investment	IG	✓
1925–1929	IG Farben investment, Oppau	48.0	RM	Investment	IG	✓
1926–1930	Research + pilot plants, Oppau and Leuna	248.9	RM	Investment	IG	✓
1930–1932	Leuna investment during the Depression	26.0	RM	Investment	IG	✓
1936	Sparte I new plant (nitrogen/hydrogenation)	38.9	RM	Investment	IG	✓
1937–1940	IG investment, Oppau	76.0	RM	Investment	IG	✓
1937–1940	IG investment, Leuna	177.0	RM	Investment	IG	✓
1941–1944	IG investment, Rhine plants (Oppau/Lu)	306.0	RM	Investment	IG	✓
1941–1944	IG investment, Leuna	229.0	RM	Investment	IG	✓

[†]Retained earnings, counted as cartel-enabled in the case-study figure.

D.1.2 Patents

Panel B of Figure 2 counts nitrogen-chemistry patents per year from the same digitized *Reichspatentblatt* corpus described in Appendix D.6. We keep patents in the CPC subclasses for inorganic nitrogen compounds and nitrogenous fertilizers (C01B, C01C, and C05C) and count distinct patents by year of grant.

D.1.3 Prices

Panel C of Figure 2 shows the price of contained nitrogen in Chilean saltpeter and sulfate of ammonia, in constant 1913 U.S. dollars per kilogram of nitrogen. We collect weekly market quotations from the *Chemiker-Zeitung* (*Chemiker-Zeitung*, 1877–1930) (Figure D.1), convert units and currencies to a per-kilogram-nitrogen basis, deflate with the U.S. consumer price index (Jordà et al., 2017), and take the annual median for each good. Before 1913, the series uses coke-oven byproduct sulfate of

ammonia as a market-price proxy. This is the same fertilizer salt, but it is recovered from coke production rather than made by synthetic ammonia fixation; Haber-Bosch output did not yet trade.

Figure D.1: Price Source: Sample Page

Nr. 87. 1928

CHEMIKER-ZEITUNG

855

Formaldehyd, 40% Vol., einschl. Korkfässchen	46,00—47,00
Glycerin, 2mal destilliert, spez. Gew. 1,260	66,00—68,00
Isobutylalkohol, 100-108°	110,00—115,00
auschl. Leihverpackung	
Nichtalkohol, technisch, 40% Gew.-%	53,50—55,00
Naphthalin in Kugeln und Schuppen	14,00—16,00
Säpaphol	70,50—71,75

Chemikalien. (Genus, Mitte Oktober.) Die Preise verstehen sich, wo nichts anderes angegeben ist, in Lire für 100

Aceton	800
Ätskali, 88-92%	217
Aetzalkali, 70-75%	125
— 15-18%	142
Alaun, kryst.	83
— mehl.	80
Amesensäure, techn., 90%	500
Ammoniak, flüssig, wasserfrei	320
— kohlensaure, Stücke	270
— kohlensaure, mehl.	270
— salpetersaure, 15-18%	92
Ammoniaklaun	122
Ammoniumphosphat	485
Ammoniumperchlorat	660
— techn.	760
Ammoniumpyrophosphat	660
Ammoniumsulfat, 20-21%	99
Stickstoff	317
Ärsäure, 90%, mehl.	99
Ärsäure, 88-100%	980
Bor, kohlensaure, gefüllt	170
Benzin	235
Benzin, feig	127
— trocken	142
Bieglasse	300
Bleisäure	320
Blei, arsenicaure, 20% AsO ₃	650
Borax, 90%, kryst.	190
— 85%, mehl.	200
— 95%, staubfrei	222
Borsäure, roh, 90%	350
— rein, große Schuppen	375
— rein, mehl.	343
Naphthalin in Stck.	160
Brenz, flüssig	160
Bromkal., rein	1520
Bromnatrium, rein	1620
Cadmium, 1 kg	25
Calciumarsenat	300
Calciumchlorid	13
Calciumnitrat	450
Calciumperphosphat, 14-16%	19
— 15-18%	43
Calciumtriphosphat, 18-18%	47
Campher, raff., 1 kg	206
Carbolsäure, weiß, kryst.	670
— flüssig, 90%	355
Chloranilin, kryst.	106
Chlorcalcium, 75-80% zu Eisenschmelzen	58
— 80-85%	149
Chloralk., 100-100	73
— 110-115°	82
— 115-120°	70
Chlorammon, geschnitten	290
Chlorammon, kryst.	290
Chloranilin, 10%	290
Chromoxyd, 88-100%, dunkel	1000
— 88-95%, hell	1700
Chromsäure, bleifrei	225
Dextrin, gelb	255
— weiß	265
Eisenessig, ausländische	145
— ausländische	95
Eisenoxyd, rot, inländische	50
— rot, spanische	50
Eisensäure, 90%	850
Eisensäure, techn., 40%	215
Fluorsäure, 90%	420
Formaldehyd, 40%	500
Gehal	620
Gehal	590
Gehal	37
Gehal	40
Gehal	270
Gehal	200
Gehal	570
Gehal	600
Gehal	285
Gehal	330
Gehal	355
Gehal	325
Gehal	500
Gehal	510
Gehal	210
Gehal	170
Gehal	500
Gehal	200
Gehal	33
Gehal	104
Gehal	38
Gehal	7
Gehal	26
Gehal	15
Gehal	87
Gehal	60
Gehal	400
Gehal	500
Gehal	640
Gehal	800
Gehal	995

Chemikalien. (Tokio, Ende September.) Die Notierungen stellen sich wie folgt:

Anorganische Chemikalien.	
Ätskali, Import, 88-92 KOH	22,00
— desgl. Japan	23,50
Ätsnatron, korn., 120-125°	9,65
50 kg	10,00
Alaun in Stck., roh	6,00
Pulv., raff.	20,00
Aluminiumsulfat, 17-18%	6,00
Ammoncarbonat	18,00—19,00
Ammonsalz, 1 t	180,00
Azeuk, weiß, pulv., 50 kg	8,50
Bariumcarbonat	28,00
Bariumchlorid, Kristallmehl, 84-96%	45,00
Dariumnitrat	25,50
Bariumsperoxyd	45,00
Bariumsulfat	5,50
Bismut, 100 kg	10,00-20,00
Bismutnigge, 50 kg	22,70
Bleiweiß, garan. rein	27,80
Blutlaugensalz, reib., Japan	42,00
— desgl. Import	42,80
— Na, gelb	30,00
rot	32,00
Borax in Stck.	9,50
— pulv., raff.	10,70
Borsäure, kryst., 100 kg	39,50
— pulv.	39,80
Calciumacetat, Japan	11,00
— desgl. Import	11,80
desgl. Grakalk, Japan	8,00
Calciumcarbonat, Japan	5,30
— desgl. Import	10,00
Calciumchlorid geschnitten, 70-75%, 1 t	120,00
— anhyd.	250,00
Chloralk., 80% . 50 kg	1,50
35% . 50 kg	5,00
Chlorammon, techn. rein, 10% 50 kg	14,50
Crakalk, 88-100% . 50 kg	11,50
Eisenvitriol, 50 kg	2,80
Gips, Japan	9,00
— desgl. Import	11,50
Glaubersalz, anhyd.,	9,50
— feine Kryst., techn.	4,10
— grob kryst.	5,00
Kalliumcarbonat, 80% Pot- sache, 50 kg	24,50
— desgl., 90%	23,50
— desgl., 95%	17,00
Kalliumchlorid	18,00
Kalliumsulfat	20,00
Kobaltchlorid	285,00
Kobaltoxyd	500,00
Kupferessig, kryst., 98-100%	19,50
Lithopone	12,50
Magnesia alba	20,00
Magnesia usta	20,00
Magnesiumsulfat	6,00
Manganoxyd (Braunstein)	5,00
Natriumacetat	15,00
Natriumbicarbonat	4,80
Natriumcarbonat, Japan	4,90
— desgl. Import	5,20
— Kristallsoda	6,00
— Waschlauge	4,00
Natriumchlorat	29,00
Natriumnitrat, 100%	15,50

Chemisch-technische Produkte. Die Regierungskommission in Saarbrücken, Abt. Volkswirtschaft, schreibt nachstehende Lieferungen aus: 1. Für die Heil- und Pflanzengast in Merzig: die Lieferung von 300 kg Aschenerbrennstoff, 30 kg Schmelz in Hoborn; 2. Für die Landeskrankenhause in Homburg: Lieferung von 2000 kg Schmierseife mit 40—42% Fettgehalt, reine Leinölwase; 1000 Zentner kohlensaure Dungkalk; 300 Pakete Streichholz, je 10 in Schachteln, 3. Für das Evangelische Knaben-Erziehungsheim in Homburg: 24 Flaschen Brennstoff, 1 Lederapparat, 100 Pakete Blitzschwärze; 10 Dosen Bärenkehl je ½ kg; 24 große Tuben Gummlösung; 200 Stück weisse Kerneise, je 200 g; 20 kg Kerneisenflocken; 50 kg Soda; 50 Pakete Schmelzphosphor, 50 kg Schmelz, 50 Dosen schwarze Schmelz je ½ kg; 20 kg Aschenerbrennstoff, je ½ kg; 20 Pakete Anbeote zu 1 sind bis 6. November, 2 und 3 bis 1. November einreichen an der oben schreibende Stelle. Die Anbeote müssen mindestens 12 Tage bindend sein. Auf die Befügung von Mustern wird Wert gelegt. Lieferung hat alsbald nach Bestellung unter gleichzeitiger Rechnungsende auf Lieferung, frei Anzahl, oder auf Rechnung, die Lieferung der Anbeote auf Erlösen von 40 t Benzin und 3 t Winteröl für Automobile vorzuziehen. Die Lieferung des Post- und Telegraphendirektion in Zagerow, von 80 t Ricinusöl (ohne Termin) das Luftschiffahrtskommando in Peterwardein, von 8 t Fernis, 3 t Ocker und 15 t Zinkweiß zum 13. November das Artilleriechiefskommando in Kragsburg von 70 t Benzin zum 6. November; die Ökonomie Abteilung des Heeresministeriums in Belgrad, auf Lieferung von 1400 t Benzin zum 3. November die Technische Abteilung des Luftschiffahrtskommando in Peterwardein. Die gleiche Stelle vergibt am 17. November die Lieferung von Aeroplanmahl und Pragens Gummi. Außerdem jeweils durch die ausschende Stelle, Sicherung zum 1. November 10% Öfterwertes. Die Staatsbahndirektion Adrag-Sud vergibt am 1. November die Lieferung ihres Bedarfs an Leinöl 1929, sowie die Lieferung größerer Mengen Benzin, Ole usw., die Direktion des Staatlichen Krankenhause in Märlich-Ostau-Zabreh am 16. November die Lieferung ihres Bedarfs an Medikamenten für die Schleisch- und Chirurgische Abteilung des Staatlichen Krankenhause in Munkacs am 14. November die Lieferung von Verbandmaterial und Medikamenten. — Die Eisenbahndirektion in Lemberg schreibt zum 16. November die Lieferung von Farben, Firnissen, Chemikalien, Gummiwaren usw. aus, und zwar des gesamten Bedarfs 1929.

Chemisch-technische Produkte. Die Kaliwerke Neu-Staßfurt Friedrichshall

Note. A market-price page (*Handelsblatt*) of the *Chemiker-Zeitung* (Nr. 87, 1928), quoting chemical prices across several markets and currencies; these quotes are the raw input to the price extraction.

D.1.4 Chilean and Synthetic Production

Panel D of Figure 2 shows fixed-nitrogen output. Chilean contained nitrogen comes from annual nitrate exports in the online *Album del Desierto* compilation (Hernández Cornejo, 1930), converted

using the nitrogen content of sodium nitrate and extended to 1930 with a League of Nations figure. The world industrial fixed-nitrogen series sums coke-oven byproduct, cyanamide, arc, and Haber-Bosch output. It splices contemporary series for 1896–1902 (Lunge, 1916), 1903–1909 (Partington and Parker, 1922), 1910–1918 (United States Army Ordnance Department and Department of Agriculture, 1922), and 1920–1930 (League of Nations, 1932). Only 1919 is interpolated. Overlapping sources agree within 2 percent in 1913 and within 4 percent in 1925 (Ernst, 1928).

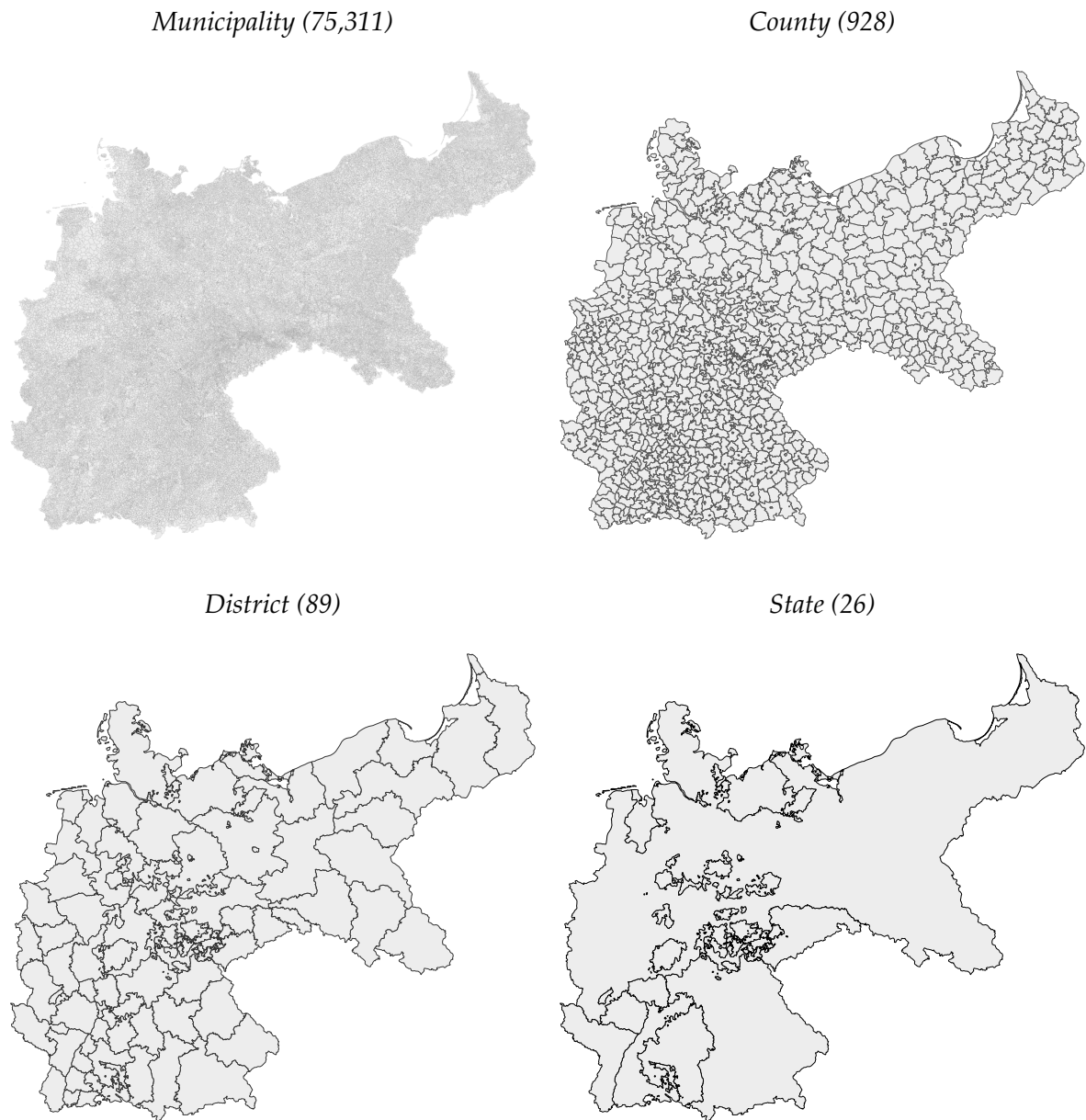
D.2 Geography and Industry

The analysis uses a common industry classification and nested spatial units. We assign each firm its modal four-digit NACE code across the handbook editions in which it appears. The two-digit code defines an industry, the three-digit code defines the product dimension of a market, and an industrial flag restricts the sample to mining, manufacturing, construction, and utilities.

To each two-digit industry we attach a set of characteristics measured outside the German cartel setting: capital intensity, skill intensity, external finance dependence, asset tangibility, and the natural-resource share from Manova (2013); contract intensity from Nunn (2007); product homogeneity from Rauch (1999); the value-to-weight ratio from the CEPII BACI trade data; and capital stock per worker and the capital-output ratio from the EU KLEMS accounts for Germany. Three further measures come from German sources dated after 1897: the joint-stock share of persons engaged, from the 1907 business census, upstreamness computed from the 1936 input–output table, and an indicator for war-relevant industries. We treat these three as descriptive rather than predetermined. Modern classifications map to NACE through weighted crosswalks.

We locate firms in three steps. County boundaries come from the census-geography GIS of the German Empire (MPIDR and CCG, 2011). We build a gazetteer of municipalities from the official register, the *Gemeindeverzeichnis* (Figure D.3), cleaning each municipality’s administrative hierarchy, its state, district, and county, and recording its population; historical coordinates come from the *Meyers Orts- und Verkehrs-Lexikon*. We geocode each firm’s headquarters to a municipality and place it in the 1882 county that contains it. From the county we assign a district, the geography of a market: Berlin stands alone, else the government region, else the province, else the state. The register records each municipality’s population at the census, which we aggregate to the census county and map for every wave (Figure D.4). The four spatial levels nest as shown in Figure D.2: municipalities within 928 counties, counties within 89 districts, and districts within 26 states.

Figure D.2: Spatial Hierarchy: Municipality, County, District, State



Note. The four nested spatial levels of the analysis; each panel aggregates the preceding level. Counties, districts, and states use the 1882 statistical geography. The 928 census counties aggregate to 89 districts (Berlin, otherwise the government region, province, or state) and then to 26 states. Municipalities are the finest layer and the unit to which headquarters are geocoded; the panel uses the 1910 *Gemeindeverzeichnis*. Panel labels report unit counts.

Figure D.3: Municipality Register: Sample Page

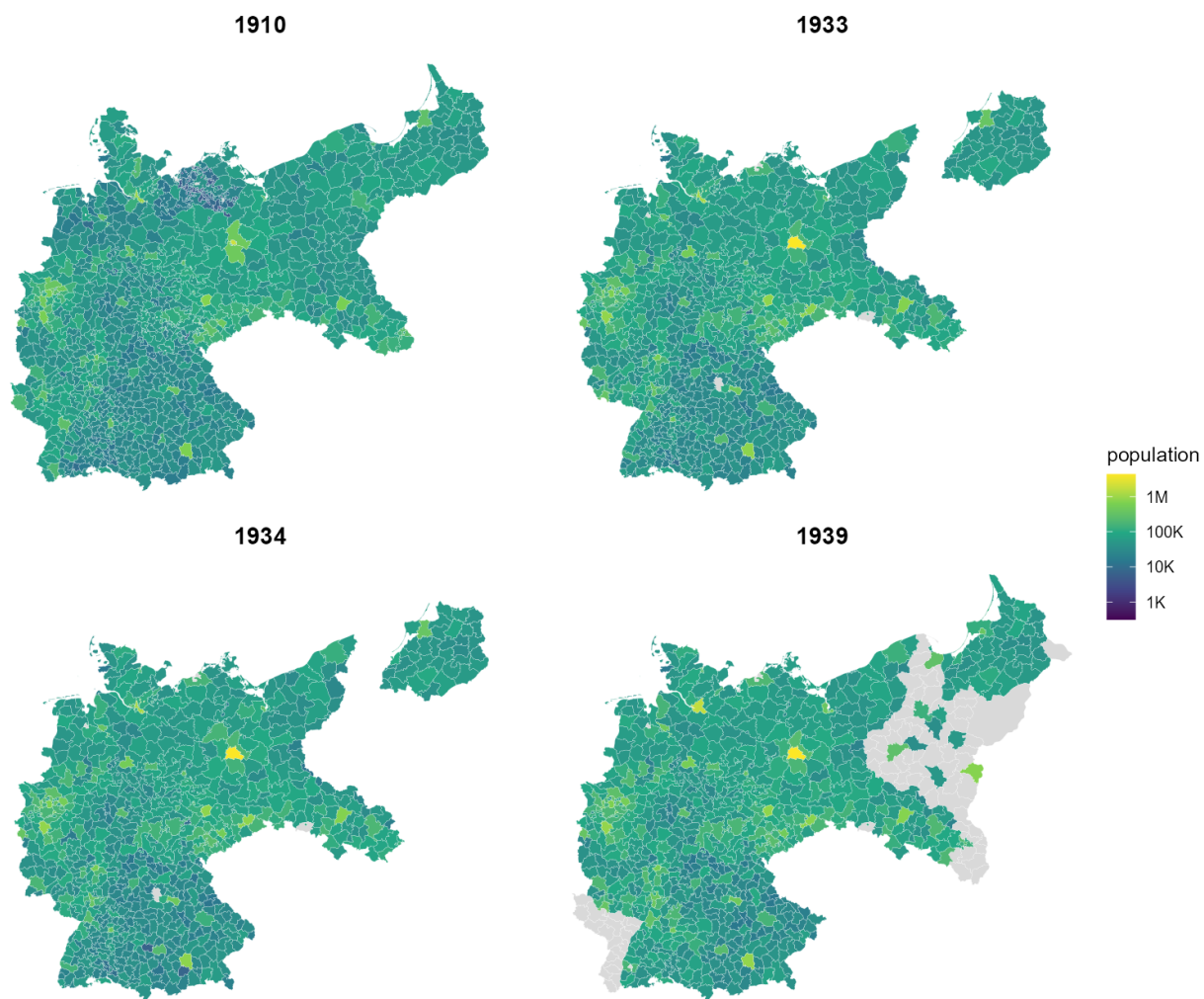
— 83 —

Systematisches Verzeichnis der Gemeinden				Provinz Sachsen 6			
				6—11			
Kleinere Verwaltungsbezirke Gemeinden	Wohn- bevölkerung am 16. Juni 1933	Kleinere Verwaltungsbezirke Gemeinden	Wohn- bevölkerung am 16. Juni 1933	Kleinere Verwaltungsbezirke Gemeinden	Wohn- bevölkerung am 16. Juni 1933	Kleinere Verwaltungsbezirke Gemeinden	Wohn- bevölkerung am 16. Juni 1933
Gemeindefreie Grundstücke (Gutsbezirke)		Reesdorf	217	Kabelitz	272	Beckendorf-Neindorf ..	813
Letzinger Heide, Anteil	—	Rietzel	272	Kade	1 014	Dalldorf	298
Kr. Haldensleben...	—	Rogäsen-Jerichow	168	Kamern	406	Dedeleben	1 682
		Rosian	588	Karow	966	Deesdorf	414
		Rottstock	248	Kirchmöser	4 593	Dingelstedt am Huy..	1 330
		Schartau	712	Kleinmangelsdorf	126	Eilenstedt	1 741
		Schermer	1 029	Kleinwulkow	183	Eilsdorf	593
7. Landkreis Jerichow I	58 139	Schopsdorf	363	Kleinwusterwitz	265	Emersleben	834
(Sitz: Burg b. M.)		Schora	299	Klietz	580	Emmeringen	145
Biederitz	3 342	Schweinitz	580	Klietznie	196	Gröningen, Stadt	3 012
Böcke	214	Stegolitz	438	Knoblauch	379	Groß Quenstedt	1 423
Brietze-Kalitz	292	Steinberg	193	Krüssau	352	Günthersdorf	99
Buckau	260	Stressow	253	Kützow	149	Gunsleben	622
Bucknitz	577	Theesen	413	Kuhlhausen	393	Hammersleben	1 682
Büden	347	Tüppel	118	Libars	190	Harsleben	2 312
Dalchau	307	Tryppelna	476	Mahlenzien	138	Heteborn	600
Dannigkow	628	Vohltz	352	Melkow	231	Hordorf	870
Detershagen	309	Wahlitz	237	Milow	1 595	Hornhausen	2 692
Dörnitz	473	Wallwitz	272	Möhlitz	222	Huy-Neinstedt	347
Dretzen	277	Walternienburg	848	Molkenberg	443	Klein Quenstedt	834
Drewitz	607	Wenzlow	332	Mützel	482	Kloster Gröningen	681
Flotz	165	Werbig	308	Neubensdorf	375	Kroppenstedt, Stadt ..	2 554
Friedensau	214	Wörmitz	533	Neuenkittsche	340	Krottorf	741
Gehrden	341	Wollin	629	Neuenmark	281	Neubrandesleben	147
Gerwisch	1 911	Woltersdorf	423	Neue Schleuse	2 135	Neuwegeleben	797
Gienecke	444	Zeddenick	399	Neuwartensleben	2 212	Nienhagen	626
Görzke	1 760	Zeppernick	417	Niebock	260	Oschersleben (Bode),	
Gommern, Stadt	4 964	Ziepel	383	Nitzahn	283	Stadt	14 144
Grabow	682	Ziesar, Stadt	2 502	Papitz	675	Ottleben	1 258
Gräben	504	Zitz	452	Parchen	1 155	Pabstorf	265
Groß Libars	609			Parey	2 773	Rodersdorf	328
Gröningen	259	Gemeindefreie		Redekin	633	Röderhof	345
Gübs	456	Grundstücke		Reesen	432	Schlanstedt	1 673
Güterglück	670	(Gutsbezirke)		Rehberg	215	Schwanebeck, Stadt ..	3 309
Hobeck	503	Gloine	196	Ragösen	318	Vogelsdorf	685
Hohenlobbes	206			Reckdorf	431	Wegleben, Stadt	3 130
Hohenwarthe	811	8. Landkreis		Sandan a./Elbe, Stadt	1 794	Wehrstedt	2 183
Hohenziatz	729	Jerichow II	69 052	Scharlisse	340	Wulferstedt	1 357
Hleburg	541	(Sitz: Genthin)		Scharteucke	237		
Isterbies	285	Altensdorf	601	Schlagenthin	1 004	Gemeindefreie	
Kämeritz	209	Altenklitsche	208	Schmetzdorf	365	Grundstücke	
Kalenberge	124	Bahmitz	230	Schönfeld	426	(Gutsbezirke)	
Klein Libars-Riesdorf	484	Bergzow	1 170	Schönhausen	2 068	Oschersleben, Forst ..	—
Königsborn	264	Böhne	388	Schollene	991		
Köpernitz	342	Brettin	695	Seedorf	132	11. Landkreis	
Körsbelitz	197	Briest	96	Steckelsdorf	469	Osterburg	45 862
Kübelitz	856	Buckow	413	Steinitz	91	Altenzaun	189
Küsel	142	Bültzer	676	Sydow	247	Arendsee, Stadt	2 480
Ladeburg	537	Derben	1 513	Tucheln	1 564	Aulosen	307
Leitzkau	1 686	Dretzel	345	Vehlen	259	Behrend	131
Loburg, Stadt	2 734	Perchels	142	Vieritz	477	Behrendorf	133
Lostau	715	Perchland	884	Viesen	340	Berge	446
Lübs	612	Fienerode	171	Warchau	322	Berikow	389
Lühe	445	Fischbeck	385	Warnau	456	Beuster	467
Magdeburgerforth ..	334	Garz	382	Woltersdorf	548	Biesenhal	137
Menz	441	Genthin, Stadt	10 472	Wulkau	533	Binde	375
Mickern, Bez. Magde-		Gladau	577	Wust	673	Bömenzien	152
burg, Stadt	1 948	Göthlin	418	Zabakuck	343	Boock	242
Möser	851	Gollwitz	142	Zorben	392	Bretsch	319
Moritz	136	Großdemsin	277	Zollchow	350	Busch	84
Moritz	576	Großmangelsdorf	242			Calberwisch	172
Nedlitz	1 111	Großwulke	852	9. Stadtkreis		Dalchau	232
Niegripp	850	Großwulkow	195	Magdeburg	306 895	Dequede	182
Niechau	551	Großwusterwitz	3 101			Dessau	258
Nietzpuhl	221	Grütz	315	10. Landkreis Oschers-		Deutsch	179
Nietzky	1 030	Güsen	1 418	leben (Bode)	61 049	Dewitz	175
Nrausdorf	161	Hohenbellin	134			Dobbrun	154
Nretzien	770	Hohengöhren	770	Adersleben	267	Drösedau	82
Nrödel	355	Hohenseeden	493	Aderstedt	829	Drösedau	172
Nandau	484	Jerchel	343	Anderbeck	1 159	Düsedau	314
Nanies	413	Jerichow, Stadt	2 720	Adersleben	82	Einwinkel	136
				Badersleben	1 676	Erleben	459

11*

Note. A page from the official *Gemeindeverzeichnis* (1933), listing municipalities within their administrative hierarchy, grouped by county and province, with the population recorded at the census of 16 June 1933.

Figure D.4: County Population by Census Wave



Note. County population, summed from municipalities in the *Gemeindeverzeichnis*, for the four register waves (1910, 1933, 1934, and 1939). Each municipality is assigned to a census county through its administrative hierarchy. Gray counties contain no municipality observed in that register wave; these include Austria and the territories annexed in 1938–39. Fill is on a log scale.

D.3 Investor Handbooks

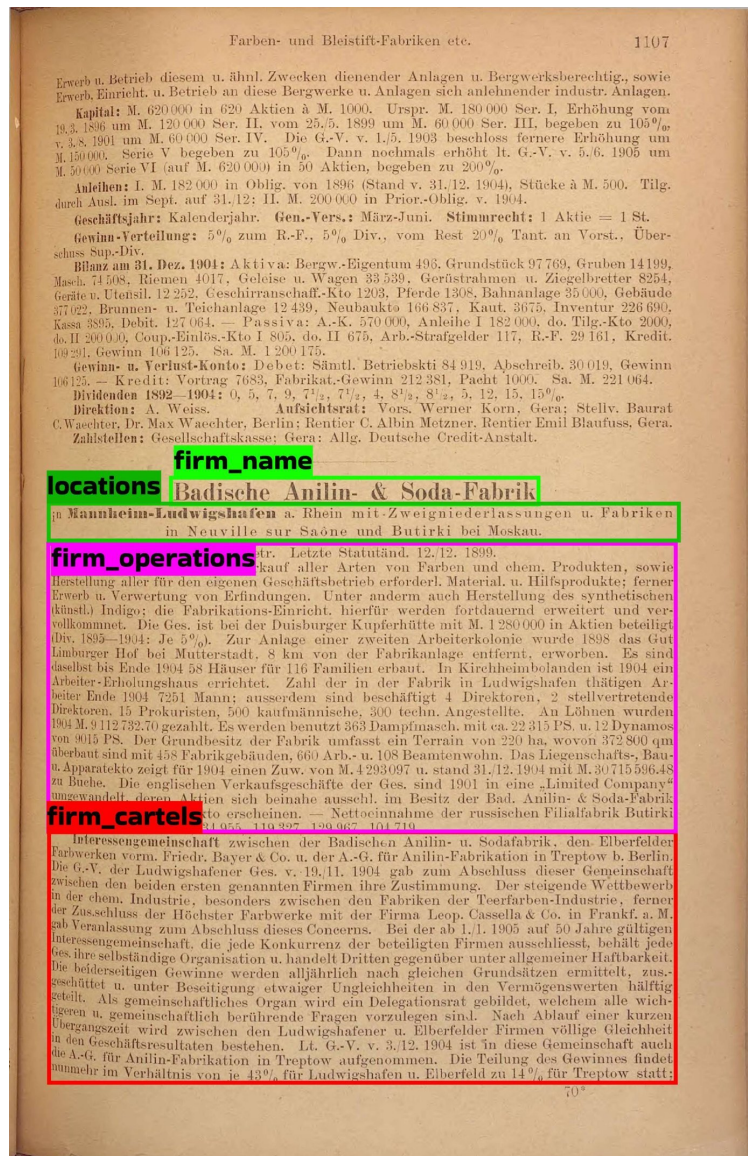
The firm panel comes from the annual investor manuals (Hertslet et al., 1882–1933; Thieme, 1897–1933). *Saling's* covers firms listed on the Berlin exchange from the 1870s; the *Handbuch* adds unlisted joint-stock firms from the late 1890s.

We convert each scanned volume to text by optical character recognition and detect the boundary of every firm entry with a layout model (Figure D.5). A large language model then reads each entry and returns its fields: the firm name, headquarters, industry description, cartel affiliations, board and management rosters, share prices, dividends, employment, financial holdings, and exports. We harmonize firm names, standardizing legal form and separating the headquarters town from the name. Because a firm recurs across volumes under variant names, we resolve firm identity over time from name embeddings and a matching step, clustered into firms and checked against a manually coded sample. We assign each firm a NACE industry code and geocode its headquarters to a county and district as described in Appendix D.2.

Most outcome and mechanism variables come from these entries. The exporter indicator is one when the operations abstract reports export activity, based on the terms *Export*, *Ausfuhr*, and *Auslandsgeschäft*. Output is reported physical output, and employment is the reported headcount. Revenue is the revenue reported in the income statement. Capital expenditure is the reported value of investment in the year; reserves are balance-sheet reserves (*Reserven*, *Rücklagen*), and the dividend rate is the reported dividend in percent of share capital. A firm's exit is dated to its last observed year and right-censored at the end of the sample. For board composition, we use titles to classify directors' bank and state ties, resolve directors across firms, and count interlocking directors who serve another firm in the same year.

Two currency events fall inside the sample: the 1923 hyperinflation and the subsequent Goldmark revaluation. The monetary outcomes we use, capital, reserves, capital expenditure, and revenue, are extracted in nominal marks and deflated to constant 1913 marks using the German consumer price index, which removes both currency events.

Figure D.5: Investor Handbook: Sample Firm Entry



Note. A firm entry from the *Handbuch der deutschen Aktiengesellschaften* (BASF, 1905). The colored boxes are the fields the layout model detects: the firm name, its locations, the operations abstract, and the cartel affiliations.

D.4 Cartel Registry

We assemble cartel membership from several sources and reconcile the records to firms. The *Kartell-Rundschau* lists the cartels covered in each issue's table of contents, which we digitize (Figure D.6); three cross-sectional surveys supply firm rosters (Reichsministerium des Innern, 1906; Silberberg, 1910; Wagenführ, 1931); and the operations abstracts name cartels to which a firm belonged. We recover these names from the language-model extraction and from direct searches of the abstract text. We resolve variant names to distinct cartels by the same embedding-and-matching procedure used for firms. The procedure records each cartel's first and last appearance in our sources; these dates need not equal formation or dissolution dates.

Figure D.6: Cartel Registry: Sample Page

Cartell-Rundschau

Zeitschrift für Cartellwesen und
verwandte Gebiete

Zweimal monatlich Einzelnummer K 1.20

Herausgegeben und redigirt von Josef Borger

Bezugspreis für Oesterreich-Ungarn 25 K pro Jahr, Deutschland und das Ausland 25 Mk.
Redaction und Administration: Wien, IV. Belvederegasse No 8

1. Jahrgang

Wien, 1. Jänner 1903

Nummer 1

Inhalt

Das Programm der Cartell-Rundschau

Der Staat und die modernen Privat-Monopole (ein Vortrag von Dr. Emil Steinbach)

Voraussichtliche Entwicklung des Cartellwesens (aus einer Broschüre von Dr. Ludw. Pöhl)

Neuordnung der Production (von Josef Borger)

finanzielle Trust-Gesellschaften („Vossische Zeitung“)

Enquete über das Cartellwesen Deutschlands (Die Vorbesprechung — Preßstimmen)

Cartelle in Oesterreich-Ungarn: Eisencartell — Feinbleichcartell — Drahtstiftcartell —
Cartell der österreichischen Emailfabriken — Cartell der Kupferwalzwerke — Kunden-
schutz-Convention im Odrauer Revier — Cementcartell — Tafelglascartell — Oester-
reichisches Spiegelglascartell — Ungarisches Glascartell — Vereinigung der Wacheleder-
Fabrikanten — Rechtsschutz-Organisation der Ledergrößen — Verband der Wigogne-
spinner — Vereinbarungen zwischen Seidenindustriellen und Cravattenerzeugern —
Papier-Union — Zuckercartell — Syrupcartell — Dextrincartell — Petroleum-Export-
Cartell — Leimcartell — Düngercartell — Schwefelsäurecartell

Cartelle in Deutschland: Kohlenyndicat — Waldburger Kundenschutz-Convention —
Zwickauer Kohlenverkaufsartell — Roheisen-Syndicate — Schweifeisencartell — Halb-
zeugverband — Schienenartell — Walzwerkyndicat — Verband oberösterreichischer Walz-
werke — Gußröhrenyndicat — Feinbleichverband — Walzdrahtverband — Drahtstift-
verband — Federstahlcartell — Abrechnungsfelle — Syndicat der Emailwerke —
Rhein-Westf. Cementvereinigung — Nordwest-Mitteldeutsches Cementyndicat — Rhein-
Westf. Ziegelyndicat — Dresdener Ziegelei-Convention — Beckumer Kaltverkaufsverein —
Glashütten-Convention — Cartelle der Textilbranche — Zuckercartell — Rohzucker-
yndicat — Zuckerraffinerie-Syndicat — Spirituscartell — Ein Syndicat der Brauereien —
Salz-Syndicat — Cartelle der heimischen Industrie — Gasesyndicat — Kalisyndicat —
Benzolyndicat — Lederlein-Syndicat — Knochenverkaufsyndicat — Fusion von
Electricitäts-Gesellschaften — Fusion von Banken — Fusion von Versicherungs-Gesell-
schaften — Syndicat von Brilet-Großhändlern — Syndicat von Schlachthöfen —
Kartoffelring

Cartelle im Ausland: Russisches Eisencartell — Russisches Nadel- und Drahtcartell —
Schwedisches Hölzlyndicat — Syndicat schwedischer Sägewerke — Italienisches
Exportcartell — Belgisches Spiegelglascartell — Holländischer Margarintrust —
Rumanisches Petroleumcartell — Englisches Kohlen-Syndicat — Fusion englischer
Stahlröhrenfabriken — Japanischer Spinnereitrust — Afrikanischer Petroleumtrust

Amerikanische und internationale Trusts: Vom amerikanischen Stahltrust — Neue Trust-
bildungen — Textiltrust — Spielwareitrust

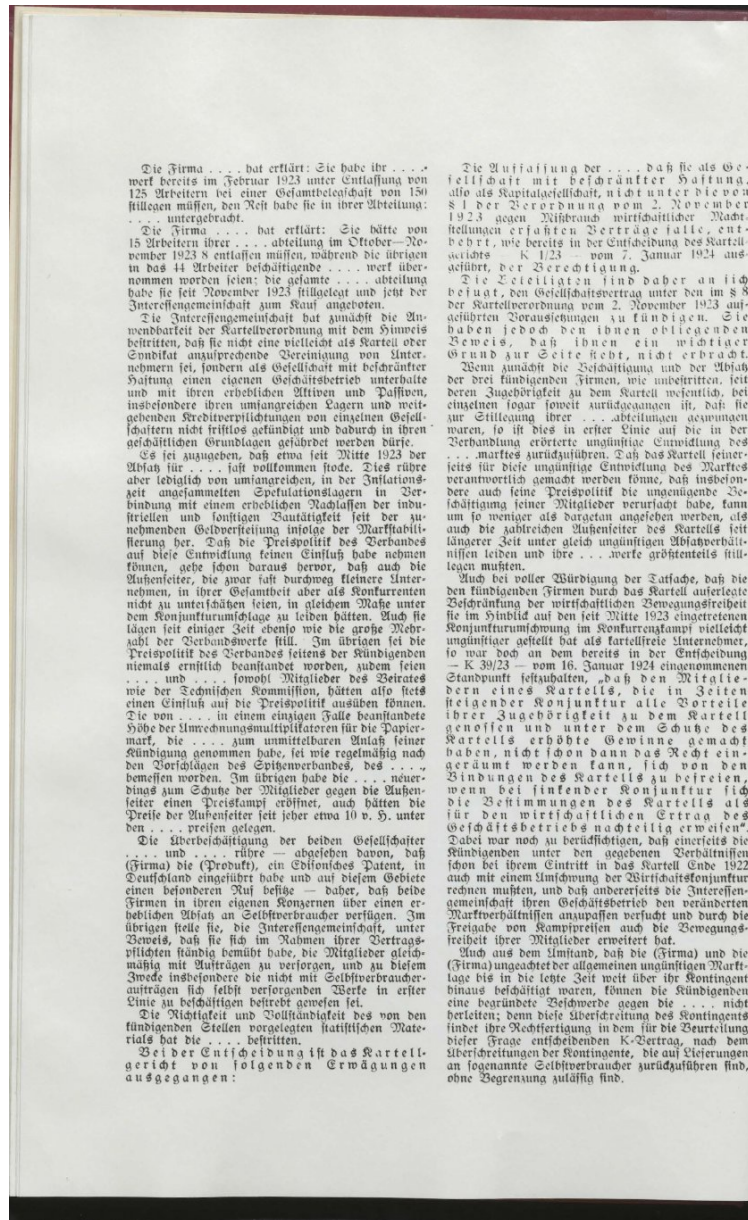
Chronik: Centralstellen für Syndicatswesen — Gerichtliche Entscheidungen über Cartelle

Note. Contents page of the *Kartell-Rundschau* (1903), which lists the cartels it covers by country and industry.

D.5 Court Decisions

We collect published cartel decisions from two principal national courts. The Imperial Court heard cartel disputes through 1923 (Reichsgericht, 1882–1933); the Cartel Court followed under the 1923 decree (Reichsverband der Deutschen Industrie, 1924–33). Figure D.7 shows a sample. A language model records the court, year, ruling, parties, industries, locations, and whether the case bears on cartel enforceability. Of the digitized decisions, 416 concern enforceability, including the 1897 wood-pulp ruling used in the instrument of Section 4.3. The model also records the contract devices each decision upheld; we verify the landmark cases by hand.

Figure D.7: Court Decision: Sample Page



Note. A reported decision of the Cartel Court, applying the Cartel Decree of 2 November 1923 to a member's right to withdraw from a cartel.

D.6 Patent Gazette

The patent indicator is one when the firm was granted a patent in the year. We collate the annual volumes of the *Reichspatentblatt* (Reichspatentamt, 1918–33), extract the grantee names (Figure D.8), and match them to firms by harmonized name.

Figure D.8: Patent Gazette: Sample Page

Patente.	
Anmeldungen. *)	
Für die angegebenen Gegenstände haben die Nachgenannten an dem bezeichneten Tage die Er- teilung eines Patentes nachgesucht. Der Gegenstand der Anmeldung ist einflusslos gegen unbefugte Be- nutzung geschützt.	
(Bekanntgemacht im Reichsanzeiger vom 12. Oktober 1911.)	
Klasse.	
1a. R. 32313. Waschverfahren für Rohseife. Otto Rindfleisch, Dortmund, Arndtstr. 53. 10. 1. 11.	direktziehenden Farbstoffen, Schwefelfarbstoffen oder Küpenfarbstoffen hergestellt sind. Farbwerke vorm. Meißner Lucius & Brüning , Höchst a. M. 9. 3. 11.
2a. S. 51203. Backofenschraube. Hercules- Werke G. m. b. H. , Berlin. 11. 5. 11.	9. C. 19883. Füllbinde mit Saugfolien, welcher die Farbe o. dgl. in einer Röhre enthält, deren Vorderende düsenförmig in die Vorsten ein- dringt. Albert Desere Cardinet , Oakland, Calif., U. St. A.; Vertr.: G. Kiehl, Pat.-Anw., Nürnberg. 10. 10. 10.
4f. C. 19574. Vorrichtung zum Formen und Abtrennen von Invertzuckertrümpfen vom Schlauch. Samuel Cohn, New York; Vertr.: G. Lamberts u. Dr. Lotterhos, Pat.-Anwälte, Berlin SW. 61. 9. 7. 10.	10a. G. 32167. Vorrichtung zum Trocknen von Brennstoffbrüpfen und zum Verfeuern des in den Brüpfen enthaltenen Bindemittels. Diamant- Brüpfen-Werke G. m. b. H. , Berlin. 27. 7. 10.
5a. P. 21890. Erdborner für Handbetrieb mit am gegabelten Ende der Bohrspindel sitzenden, an seinem unteren Ende mit verschränkten Zähnen versehenen und einen Grundbohrer aufzunehmenden Bohrgehäuse. Max Braun , Rosenberg, Ob.-Pfalz. 23. 4. 10.	12f. S. 58694. Verfahren zur Darstellung von Ammoniak aus seinen Elementen mittels Ka- talytoren. Sodische Anilin- & Soda-Fabrik , Ludwigshafen a. Rh. 17. 5. 10.
25. W. 20000. Vorrichtung zum Aufschneiden	12f. S. 60999. Verfahren zur katalytischen Darstellung von Ammoniak aus den Elementen unter Verwendung reinen Eisens als Kontakt- substanz. Sodische Anilin- & Soda-Fabrik , Ludwigshafen a. Rh. 29. 11. 10.
	12f. G. 33330. Verfahren zur Gewinnung von Cyanwasserstoffäure aus Gasen durch Absorption in alkoholischer Alkallauge. Gaston Philippe Gutguar , Melun, Seine et Oise, u. Henri Louis Adolphe Marie Wairigant , Lille, Nord-Franke; Vertr.: Dr. P. Herchland, Pat.-Anw., Berlin W. 30. 20. 1. 11.

Note. Grant listing from the *Reichspatentblatt* (1911), showing an ammonia-synthesis patent.

D.7 Input–Output Table

To measure exposure to cartelized inputs, we use a reconstructed 1936 input–output table of German industry in the digitized form provided by its authors (Fremdling and Staeglin, 2014a; 2014b). We combine each input share with the supplying industry’s time-varying cartel share. Applying the 1936 input shares to earlier years assumes that broad production linkages are sufficiently stable over the sample period.

D.8 Industrial Censuses

We assemble a county–industry panel of employment from the five industrial censuses of 1882, 1895, 1907, 1925, and 1933 (Figure D.9). We harmonize the census-native industries to two-digit NACE and place each county on a spatial unit held consistent across the five waves, giving employment by county, industry, and census year.

Figure D.9: Industrial Census: Sample Table

258 Übersicht sämtlicher am 1. Dezember 1875 erhobenen Gewerbebetriebe in

Staaten und Landestheile.	Betriebe überhaupt.												A. Betriebe ohne					
	Zahl der Betriebe.		Zahl der Geschäftsleiter.		Zahl der Gehülfen und Arbeiter.		Zahl der Lehrlinge.		Zusammen Personen (Sp. 4–9).			Webstühle, (Wirk-) Strumpf- stühle, Nähmaschinen mit Trittbewegung.	Zahl der Betriebe.		Zahl der Geschäftsleiter.			
	Haupt- betriebe.	Neben- betriebe.	Männlich.	Weiblich.	Männlich.	Weiblich.	Männlich.	Weiblich.	Männlich.	Weiblich.	Ueber- haupt.		Haupt- betriebe.	Neben- betriebe.	Männlich.	Weiblich.		
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.
Noch: I. Preussen.																		
19. Schleswig	10	4	8	—	38	5	—	—	46	5	51	—	—	—	7	4	5	—
20. Hannover	5	2	7	—	113	24	—	—	120	24	144	—	—	—	1	1	1	—
21. Hildesheim	18	—	16	1	86	2	—	—	102	3	105	—	—	—	12	—	11	1
22. Lüneburg	1	1	1	—	11	—	—	—	12	—	12	—	—	—	—	—	—	—
23. Stade	3	—	3	—	23	2	—	—	26	2	28	—	—	—	2	—	2	—
24. Osnabrück	3	—	2	1	27	4	—	—	29	5	34	—	—	—	—	—	—	—
25. Aurich	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26. Münster	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
28. Arnberg	2	2	3	—	7	—	—	—	10	—	10	—	—	—	2	1	3	—
29. Kassel	9	3	9	—	91	5	1	—	101	5	106	—	—	—	5	2	5	—
30. Wiesbaden	21	6	24	1	162	—	4	—	190	1	191	—	—	—	10	—	8	1
31. Koblenz	4	2	6	—	35	1	—	—	41	1	42	—	—	—	—	1	—	—
32. Düsseldorf	32	6	43	3	865	42	8	—	916	45	961	—	—	—	13	3	13	1
33. Köln	12	10	11	1	55	—	1	—	67	1	68	—	—	—	5	2	4	—
34. Trier	2	1	2	—	11	—	—	—	13	—	13	—	—	—	1	—	1	—
35. Aachen	7	2	8	1	50	—	—	—	58	1	59	—	—	—	5	1	4	1
36. Sigmaringen	1	—	1	—	—	—	—	—	1	—	1	—	—	—	1	—	1	—
Noch: Nach Regierungs- bezw. Landraths-Bezirken.																		
1. Preussen	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
2. Brandenburg	40	10	45	1	453	33	15	4	513	38	551	—	—	—	22	4	24	—
3. Pommern	5	—	3	1	69	4	—	—	72	5	77	—	—	—	2	—	2	—
4. Posen	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
5. Schlesien	20	5	16	2	129	67	—	—	145	69	214	—	—	—	16	1	12	2
6. Sachsen	12	11	16	—	85	3	—	—	101	3	104	—	—	—	7	5	8	—
7. Schleswig-Holstein	10	4	8	—	38	5	—	—	46	5	51	—	—	—	7	4	5	—
8. Hannover	30	4	29	2	260	32	—	—	289	34	323	—	—	—	15	1	14	1
9. Westfalen	2	3	3	—	7	—	—	—	10	—	10	—	—	—	2	2	3	—
10. Hessen-Nassau	30	9	33	1	253	5	5	—	291	6	297	—	—	—	15	2	13	1
11. Rheinland	57	21	70	5	1 016	43	9	—	1 095	48	1 143	—	—	—	24	7	22	2
Dazu Hohenzollern	1	—	1	—	—	—	—	—	1	—	1	—	—	—	1	—	1	—
Preussischer Staat	207	69	224	12	2 310	192	29	4	2 563	208	2 771	—	—	—	111	28	104	6
II. Bayern.																		
1. Oberbayern	17	3	15	3	48	19	3	—	66	22	88	—	—	—	15	3	12	3
2. Niederbayern	2	2	2	—	—	—	—	—	2	—	2	—	—	—	2	1	2	—
3. Pfalz	22	8	21	1	114	10	3	—	138	11	149	—	—	—	18	7	17	1
4. Oberpfalz	11	1	11	—	197	82	6	—	214	82	296	—	—	—	7	1	6	—
5. Oberfranken	9	—	9	1	136	42	—	—	145	43	188	—	—	—	7	—	5	1
6. Mittelfranken	230	15	154	93	1 112	523	39	2	1 305	618	1 923	—	—	—	195	4	108	91
7. Unterfranken	13	1	17	1	188	20	9	—	214	21	235	—	—	—	5	1	4	1
8. Schwaben	7	1	7	—	21	1	2	—	30	1	31	—	—	—	5	1	5	—
Zusammen	311	31	236	99	1 816	697	62	2	2 114	798	2 912	—	—	—	254	18	159	97

Anmerkung. Wegen der mit kleinen Ziffern unter der Linie aufgeführten Zahlen siehe Bemerkung 3 auf Seite 1.

Note. A page from an imperial industrial census (*Gewerbestatistik*, here the enumeration of 1 December 1875), tabulating establishments and employment by state and province; the five census waves used in the analysis (1882–1933) follow the same tabular form.

D.9 Firm War Involvement

We construct three firm-level records of war-economy involvement (Figure D.10). For wartime production, we collect from the files of the Imperial Chancery the directors who sat on the boards coordinating national industrial production, and mark a firm whose director headed such a board. For procurement, we mark a firm whose handbook entry between 1918 and 1933 reports war-supply production, keyed on *Kriegslieferung* and related terms; 882 firms qualify. For military innovation, we use the secret wartime patents, published only after 1945, and count those matched to each firm; 370 firms hold at least one.

Figure D.10: War-Economy Record: Sample

— 5 — 4

Name	Vorsitzende und Geschäftsführer	Geschäftsräume, Fernsprecher, Telegrammadresse	Aufgaben
6. Kommissar für die Bewirtschaftung verfalliger und verdichteter Gase sowie der dazu erforderlichen eisernen Flaschen	Wirtl. Geh. Oberregierungs- rat und vortragender Rat im Ministerium für Handel und Gewerbe Jaeger	Berlin W 9, Köthener Str. 44 II. Amt Nollendorf 3616	Regelung der Herstellung und des Verbrauchs von ver- falligen und verdichteten Gasen sowie der dazu er- forderlichen eisernen Fla- schen.
7. Reichskommissar für Stickstoff- wirtschaft. Untersteht gemäß § 1 der Bekanntmachung vom 18. 1. 1917 (Reichs-Gesetzbl. S. 59) dem Kriegsamt	Rittmeister Buch in Kriegs- amt (Waffen- und Munici- tions-Beschaffungs-Amt)	Berlin W 15, Kurfürsten- damm 193/194. Amt Stein- platz 6940 bis 6949, 13105 bis 13109, 13112 bis 13123	Regelung der Herstellung und des Verbrauchs von Stick- stoff sowie des Verkehrs mit Stickstoff.
8. Reichskommissar für die Kohlen- verteilung Dem Kriegsamt angegliedert gemäß § 2 der Bekanntmachung vom 28. 2. 1917 (Reichs-Gesetzbl. S. 193) Abteilung für Ausfuhr nach neu- tralen Staaten: Kohlenausfuhrstelle a) Abteilung Ost b) Abteilung West Abteilungen für Bearbeitung der Angelegenheiten, die Elektrizi- tät, Gas usw. betreffen: 1. Allgemeine Abteilung für Elektrizität, Gas usw. 2. Abteilung für Elektrizität 3. Abteilung für Gas und Wasser 4. Abteilung für Heizung Geschäftsstellen: a) Amtliche Verteilungsstelle für schlesische Steinkohle b) Rheinisch-Westfälisches Koh- len Syndikat (als amtliche Ver- teilungsstelle für rheinisch- westfälische Steinkohle) c) Amtliche Verteilungsstelle für die Steinkohlengruben des Aachener Reviers	Reichskommissar: Geh. Berg- rat Stutz Stellvertreter: Geh. Re- gierungsrat Neil Direktor Böghow Vertreter für a: Ballmich- rath Vertreter für b: Wipperf Leiter: Bergrat Dietrich Leiter: Generalsekretär Zettmar Leiter: Direktor Tempelius Leiter: Direktor Dietrich Leiter: Bergwerksdirektor Schertamp Leiter: Direktor Schornstein	Berlin W 62, Wichmannstr. 19. Fernsprecher für den Stadt- verkehr: Amt Nollendorf 3200 bis 3211, für den Fern- verkehr: Amt Nollendorf 3212 bis 3229. Tel.-Adr. »Kohlenausgleich Berlin« Geschäftsräume der Kohlen- ausfuhrstelle und Abteilung a wie vor. Fernsprecher: Amt Nollendorf 3197 bis 3198. Tel.-Adr. »Kohlenausfuhr Berlin« Zu b: Duisburg, Feldstr. 11. Fernsprecher: Duisburg 715. Tel.-Adr. »Kohlenausfuhr Duisburg« Zu 1 bis 4: Berlin SW 11, Königsgraben Str. 28. Fern- sprecher: Amt Nollendorf 4253 bis 4254. Tel.-Adr. »Kraftlichtkohle« Berlin W 8, Unter den Linden 32. Fernsprecher: Amt Zen- trum 1548, 1558/59. Tel.- Adr. »Schleikohle Berlin« Essen, Frau-Berta-Krupp- Str. 2. Fernsprecher: Essen 8290 bis 8292. Tel.-Adr. »Kohlen Syndikat Essen« Kohlscheid (Bez. Aachen). Fernsprecher: Aachen 1264. Tel.-Adr. »Verteilungsstelle Kohlscheid«	Regelung des Verkehrs mit Steinkohlen, Braunkohlen, Scheitels und Reis auf Grund der Bundesratsver- ordnung vom 24. 2. 1917 (Reichs-Gesetzbl. S. 167), ferner Regelung der Erzeu- gung, der Fortleitung und des Verbrauchs von Elek- trizität und Gas sowie von Dampf, Druckluft, Heiß- und Leitungswasser auf Grund der Bundesratsverordnung vom 21. 6. 1917 (Reichs- Gesetzbl. S. 543).

2

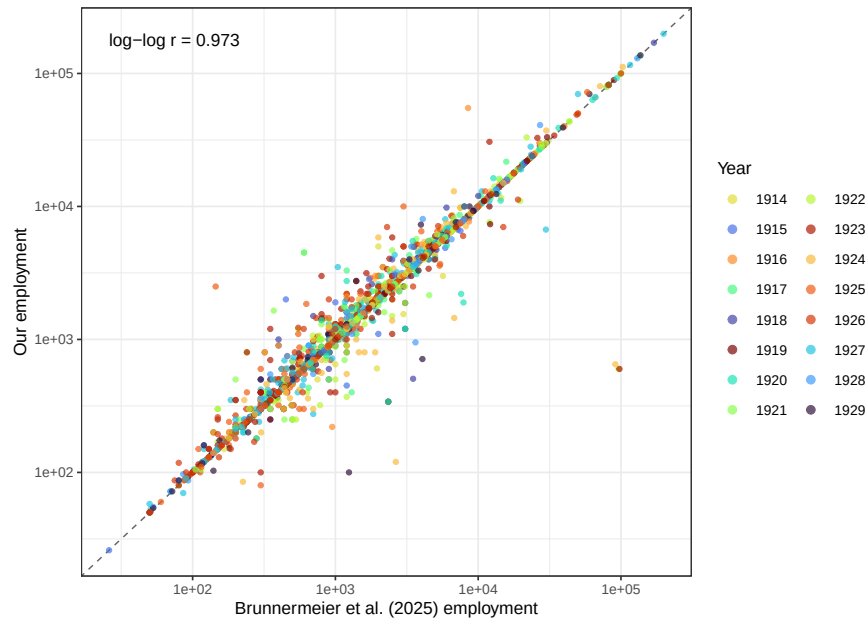
Note. A page from the Imperial Chancery register of war corporations (*Kriegsgesellschaften*, 1918), listing the boards that coordinated wartime production, among them the Reich commissioners for coal distribution and for nitrogen and the Rhenish-Westphalian Coal Syndicate acting as official distributor.

D.10 Validation

We check the extracted panel against an external benchmark. Brunnermeier et al. (2025) hand-digitize *Saling's* for 1914–1929 in the same setting. Matching firm by firm and year by year, our

extracted employment lines up along the 45-degree line with theirs, which reads the same records through an independent, manual process (Figure D.11). The comparison covers the hyperinflation years, when the underlying entries are hardest to read.

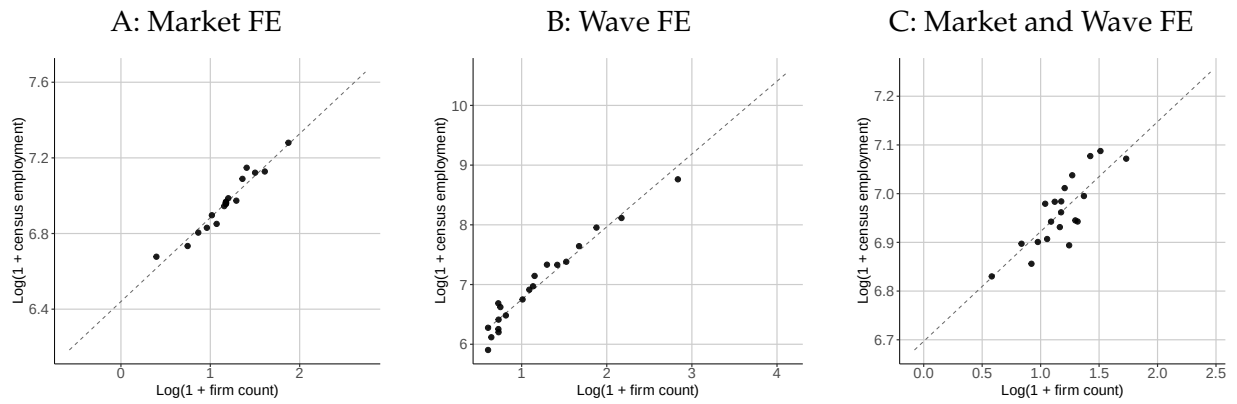
Figure D.11: Validation: Brunnermeier et al. (2025) 1914–1929



Note. Firm-year employment from our extraction, matched firm by firm and year by year to the hand-digitized firm panel (Brunnermeier et al., 2025). Each point is a firm-year, with both axes on a log scale and points colored by year; the diagonal is the 45-degree line.

Representativeness. The firm panel samples joint-stock companies rather than all firms, so we compare its coverage with the broader industrial economy. We define a market as a district by a three-digit NACE industry, count panel firms near each census wave, and match this count to census employment by market and wave (Appendix D.8). Figure D.12 plots census employment against firm counts, both as the logarithm of one plus the value. The panels remove market fixed effects (Panel A), wave fixed effects (Panel B), or both (Panel C). The relationships are positive, showing that panel-firm counts covary with census employment. They do not establish that the panel is representative in levels or trends.

Figure D.12: Representativeness: Firm Counts and Census Employment



Note. Binned scatter of census employment against the count of joint-stock firms in a market, a district by three-digit NACE industry, both as the logarithm of one plus the value. Firm counts and census employment are matched on market and census wave. Each panel removes a different set of fixed effects from both axes before binning: market (Panel A), census wave (Panel B), and market and wave (Panel C). Each point is a ventile of markets and the dashed line is the market-level fit.

E Robustness

This appendix addresses four concerns from Section 4.2: selection into cartelization, omitted market-level shocks, contamination of the comparison group, and sensitivity to the estimator, sample, and measurement. The figures report estimates for the seven outcomes of Table 1. Unless noted, the specification and sample follow Section 5. The final subsection reports table-based checks for the financing and governance results.

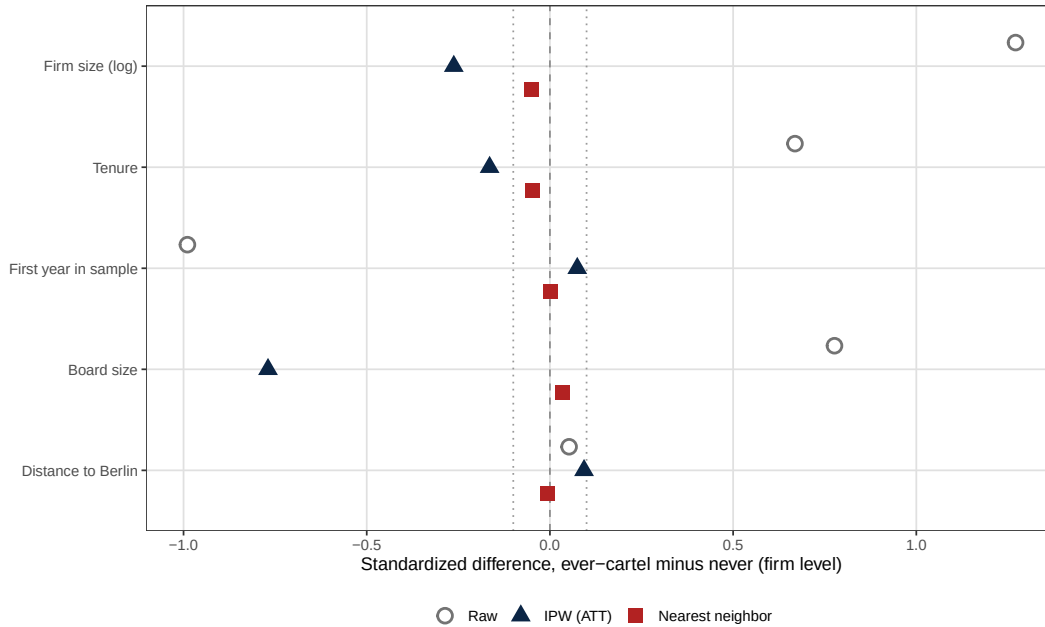
E.1 Selection and Differential Trends

This subsection checks balance on predetermined characteristics, selection into cartelization, and pre-entry trends.

E.1.1 Balance and Matching

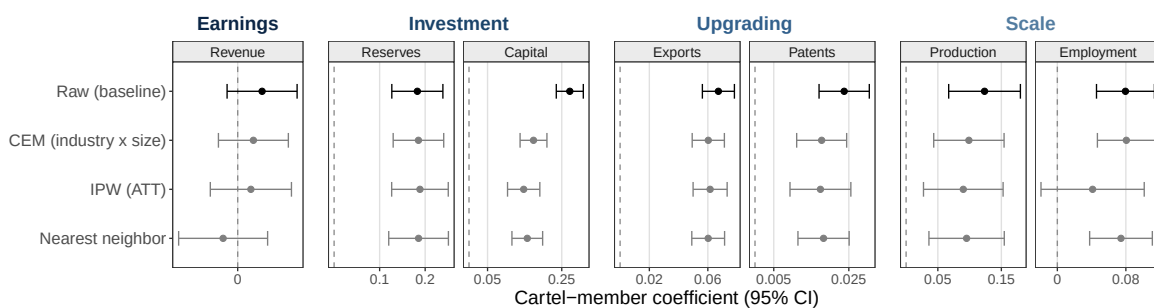
Cartel members differed modestly from nonmembers on observable characteristics. We summarize each firm by size, tenure, first year in the sample, board size, distance to Berlin, and industry, and estimate its propensity to ever enter a cartel. The area under the receiver-operating-characteristic curve is 0.88. Propensity-odds weighting and nearest-neighbor matching reduce the standardized differences (Appendix Figure E.1). Estimates under these methods and under coarsened exact matching are broadly similar to the baseline, though precision and magnitudes vary (Appendix Figure E.2). We do not match on pre-entry outcomes. For eventual members, characteristics are measured in the year before entry; for never-members, they are measured in the last observed year. Because this timing differs across groups, Appendix Figure E.3 instead measures characteristics in each firm's first observed year; the estimates are similar.

Figure E.1: Pre-Cartel Balance across Matching Approaches



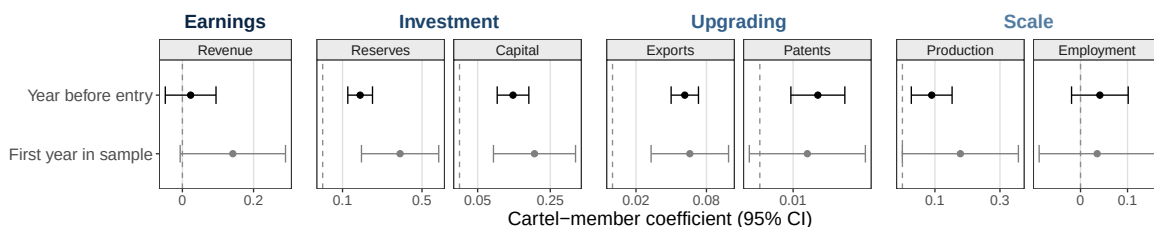
Note. Firm-level standardized differences (ever-cartel minus never-cartel, in pooled-standard-deviation units) in pre-cartel characteristics, for the raw sample and for two propensity-based reweightings: propensity-odds weighting to the treated and 1:1 nearest-neighbor matching on the propensity score. The dotted lines mark ± 0.1 .

Figure E.2: Firm Estimates under Matching and Reweighting



Note. Cartel-member coefficient with 95% confidence intervals for each outcome, estimated with firm and year fixed effects on the raw sample and under the two reweightings of Appendix Figure E.1 plus coarsened exact matching on industry by size quartile. Standard errors are clustered by firm.

Figure E.3: Matched Estimates under Two Control-Timing Choices



Note. Cartel-member coefficient with 95% confidence intervals for each outcome, estimated with firm and year fixed effects under propensity-odds weighting to the treated. The predetermined matching characteristics are measured either at the year before cartel entry (never-members: their last observed year) or at the firm's first year in the sample. Standard errors are clustered by firm.

Appendix Tables E.1 through E.4 report the four main outcomes for the complete-case sample and each matching approach, including observation and firm counts.

Table E.1: Firm Outcomes on the Matched Sample

	Earnings	Investment		Upgrading		Scale	
	Revenue	Reserves	Capital	Exports	Patents	Production	Employment
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Cartel Member	0.04	0.18***	0.27***	0.07***	0.02***	0.12***	0.08***
	(0.03)	(0.03)	(0.02)	(0.01)	(0.00)	(0.03)	(0.02)
R ²	0.94	0.82	0.86	0.60	0.49	0.99	0.94
Observations	37,292	169,976	195,710	272,987	272,987	51,375	38,588
Firms	6,203	15,589	20,905	24,826	24,826	3,755	3,543
Years	51	51	51	52	52	52	52
Outcome def.	(log)	(log)	(log)	(0/1)	(0/1)	(log)	(log)
Outcome mean	13.88	11.14	13.41	0.07	0.05	15.29	6.34
Standard errors	Firm	Firm	Firm	Firm	Firm	Firm	Firm
Firm fixed effects	✓	✓	✓	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓	✓	✓	✓

Note. Two-way fixed-effects estimates on the matched sample of firms with complete predetermined characteristics, un-weighted. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

Table E.2: Firm Outcomes under Coarsened Exact Matching

	Earnings	Investment		Upgrading		Scale	
	Revenue	Reserves	Capital	Exports	Patents	Production	Employment
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Cartel Member	0.03	0.19***	0.17***	0.06***	0.02***	0.10***	0.08***
	(0.03)	(0.03)	(0.02)	(0.01)	(0.00)	(0.03)	(0.02)
R ²	0.91	0.78	0.81	0.51	0.50	0.98	0.93
Observations	36,086	163,884	186,906	257,790	257,790	51,059	38,155
Firms	5,903	14,804	19,419	22,687	22,687	3,714	3,468
Years	51	51	51	52	52	52	52
Outcome def.	(log)	(log)	(log)	(0/1)	(0/1)	(log)	(log)
Outcome mean	14.61	12.05	14.22	0.10	0.08	15.99	6.54
Standard errors	Firm	Firm	Firm	Firm	Firm	Firm	Firm
Firm fixed effects	✓	✓	✓	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓	✓	✓	✓

Note. Two-way fixed-effects estimates weighting nonmembers by coarsened exact matching on industry by size quartile. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

Table E.3: Firm Outcomes under Inverse-Propensity Weighting

	Earnings	Investment		Upgrading		Scale	
	Revenue	Reserves	Capital	Exports	Patents	Production	Employment
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Cartel Member	0.02	0.19***	0.15***	0.06***	0.02***	0.09***	0.04
	(0.04)	(0.03)	(0.02)	(0.01)	(0.00)	(0.03)	(0.03)
R ²	0.91	0.78	0.81	0.51	0.49	0.98	0.92
Observations	37,292	169,976	195,710	272,987	272,987	51,375	38,588
Firms	6,203	15,589	20,905	24,826	24,826	3,755	3,543
Years	51	51	51	52	52	52	52
Outcome def.	(log)	(log)	(log)	(0/1)	(0/1)	(log)	(log)
Outcome mean	14.75	12.31	14.38	0.10	0.08	16.01	6.70
Standard errors	Firm	Firm	Firm	Firm	Firm	Firm	Firm
Firm fixed effects	✓	✓	✓	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓	✓	✓	✓

Note. Two-way fixed-effects estimates weighting nonmembers toward the treated by their propensity odds. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

Table E.4: Firm Outcomes under Nearest-Neighbor Matching

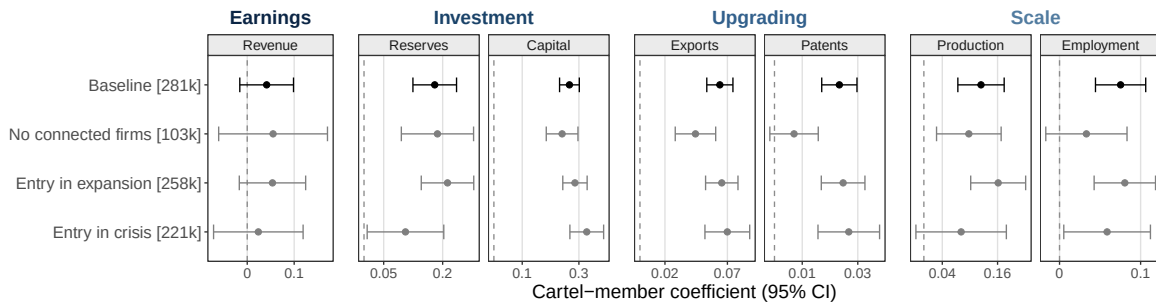
	Earnings	Investment		Upgrading		Scale	
	Revenue	Reserves	Capital	Exports	Patents	Production	Employment
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Cartel Member	-0.03	0.19***	0.16***	0.06***	0.02***	0.10***	0.07***
	(0.04)	(0.03)	(0.02)	(0.01)	(0.00)	(0.03)	(0.02)
R ²	0.91	0.77	0.81	0.51	0.49	0.98	0.93
Observations	21,926	82,693	88,898	106,478	106,478	32,621	30,299
Firms	2,695	4,768	5,205	5,398	5,398	2,052	2,233
Years	51	51	51	52	52	52	52
Outcome def.	(log)	(log)	(log)	(0/1)	(0/1)	(log)	(log)
Outcome mean	14.61	12.21	14.33	0.10	0.08	16.05	6.57
Standard errors	Firm	Firm	Firm	Firm	Firm	Firm	Firm
Firm fixed effects	✓	✓	✓	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓	✓	✓	✓

Note. Two-way fixed-effects estimates on 1:1 nearest-neighbor matches on the propensity score within a caliper. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

E.1.2 Selection into Cartelization

Two further checks address selection into cartel entry. First, we exclude firms that had a state-affiliated director before entry (Appendix Figure E.4). The estimates are less precise in this smaller sample but broadly similar. Second, we separate firms whose recorded entry occurred in an expansion year from those entering during the crises of 1900–01, 1907–08, 1913, 1919, 1923, or 1930–32, retaining never-members as comparisons. This split concerns firm entry into a cartel, not cartel formation. The estimates are similar across the two entry-timing groups.

Figure E.4: Firm Estimates by Selection into Cartelization



Note. Cartel-member coefficient with 95% confidence intervals for each outcome, each with firm and year fixed effects and standard errors clustered by firm. Politically connected firms are those that seated a state-affiliated director in their pre-entry years. The expansion and crisis rows keep every never-member firm and restrict cartel members to those whose entry year falls in an expansion or a crisis year, respectively. The count in brackets after each row label is the number of firm-year observations in that sample.

E.1.3 Pre-Trends

Our design relies on a parallel trend assumption. We test whether the observed pre-entry leads are jointly zero. The sample includes never-members and the not-yet-treated years of eventual members; all observations at or after entry are omitted. With firm-clustered standard errors, the test does not reject for patenting ($p=0.019$) and rejects for exporting ($p<0.0001$), employment ($p<0.0001$), and output ($p<0.0001$) (Appendix Table E.5). Market clustering gives similar conclusions. These results weaken a parallel-trends interpretation for exporting, output, and employment. A relative-magnitudes calculation for exporting shows that its post-entry estimate remains significant for deviations up to 0.00 times the largest estimated pre-period coefficient, but this calculation does not eliminate the observed pre-trend.

Table E.5: Joint Pre-Trend Tests

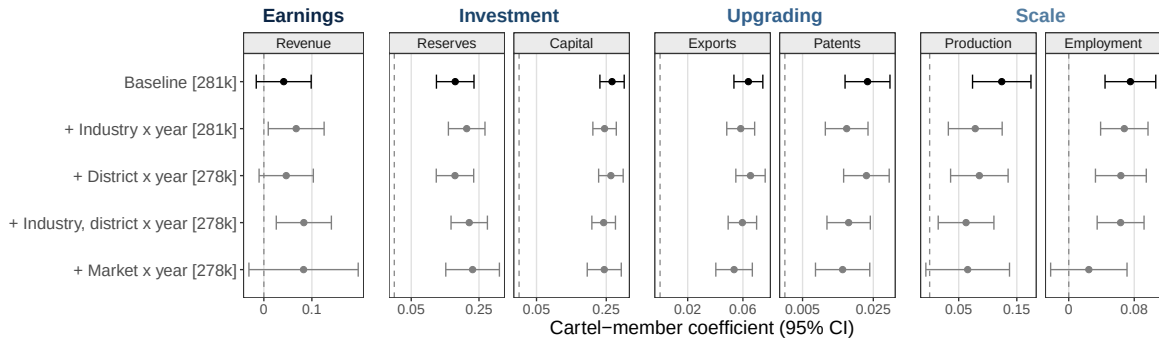
	Patents	Exports	Production	Employment	Capital
Joint pre-trend p (firm-clustered)	0.019	<0.0001	<0.0001	<0.0001	<0.0001
Joint pre-trend p (market-clustered)	0.024	<0.0001	<0.0001	<0.0001	<0.0001
Leads tested	4	4	4	4	4

Note. Joint Wald test that all pre-treatment leads (relative years -5 to -2 , reference -1) are zero, from a leads-only regression on never-member firms and the not-yet-treated years of eventual cartel members with firm and year fixed effects, reported with firm-clustered and market-clustered p -values. A market is a NACE three-digit industry by district cell.

E.2 Omitted Market-Level Shocks

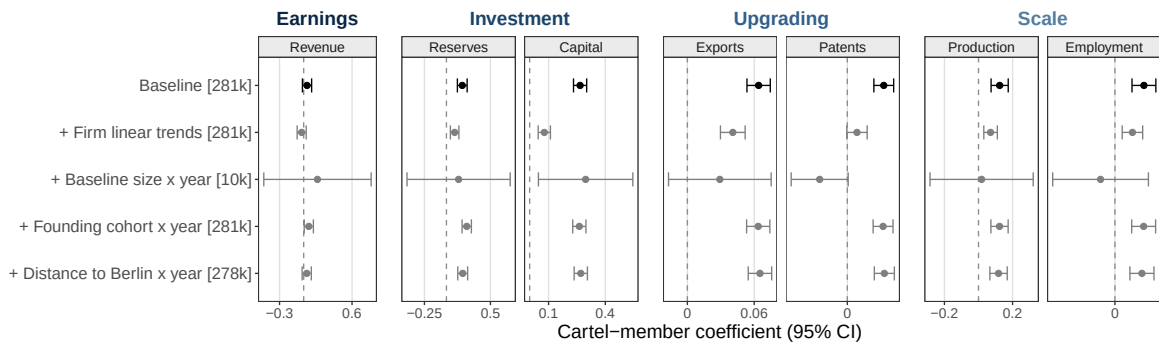
A market-level shock that coincided with cartel formation could drive the results. We absorb such shocks with progressively richer fixed effects. To the firm and year fixed effects of the baseline we add, in turn, industry-by-year fixed effects (a separate time path for each three-digit industry), district-by-year fixed effects, firm-specific linear trends, the predetermined baseline-year size quartile interacted with year, founding-cohort-by-year fixed effects, distance to Berlin interacted with year, and, most demanding, market-by-year fixed effects, where a market is a NACE three-digit industry by district cell (Appendix Figures E.5 and E.6). Distance to Berlin proxies access to Reichsbank credit and the financial center. The market-by-year fixed effects absorb any shock specific to a market-year and identify the coefficient from cartel members and nonmember firms within the same market-year, the most direct test of the market-shock concern. Appendix Table E.6 reports the four main outcomes under the specification that adds both industry-by-year and district-by-year fixed effects, shown in full. We also drop the sectors most exposed to policy, excluding in turn those coded as strategic, state-important, subject to compulsory cartels, or linked to government procurement, and the war-relevant industries of Kocka (1984) (Appendix Figures E.7 and E.8); Appendix Table E.7 reports the four main outcomes on the sample that drops all of these sectors at once. The estimates change little, including under the market-by-year fixed effects.

Figure E.5: Firm Estimates across Fixed-Effect Specifications



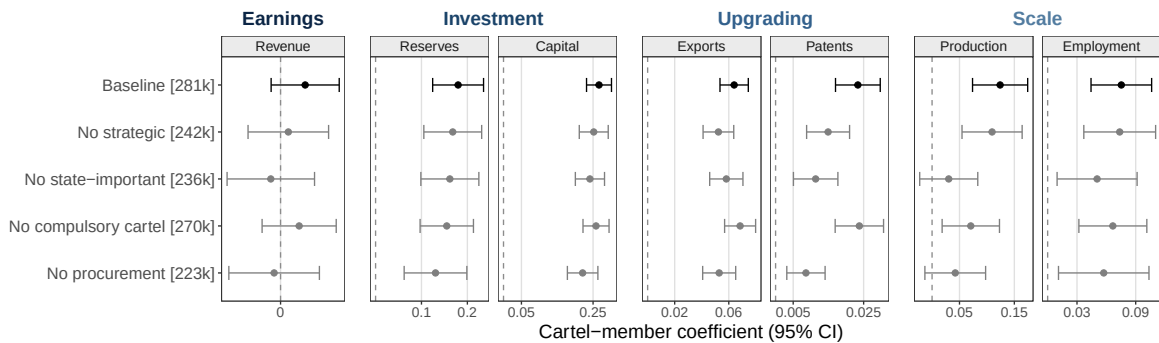
Note. Cartel-member coefficient with 95% confidence intervals for each outcome, adding to the firm and year fixed effects of the baseline the fixed effects listed on the vertical axis. A market is a NACE three-digit industry by district cell. Standard errors are clustered by firm. The count in brackets after each row label is the number of firm-year observations in that sample.

Figure E.6: Firm Estimates with Trends and Predetermined Controls



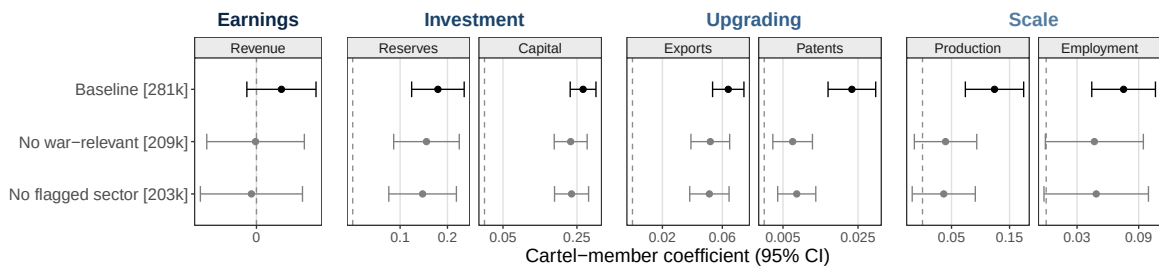
Note. Cartel-member coefficient with 95% confidence intervals for each outcome, adding to the firm and year fixed effects of the baseline the firm-specific linear trends or the predetermined characteristics interacted with year listed on the vertical axis. Firm size enters as the predetermined baseline-year size quartile interacted with year. Standard errors are clustered by firm. The count in brackets after each row label is the number of firm-year observations in that sample.

Figure E.7: Firm Estimates Excluding Policy-Exposed Sectors



Note. Cartel-member coefficient with 95% confidence intervals for each outcome, excluding in turn the sectors flagged as strategic, state-important, subject to compulsory cartels, or linked to government procurement. The sector flags are manually coded at the industry-division level and are approximate. The count in brackets after each row label is the number of firm-year observations in that sample.

Figure E.8: Firm Estimates Excluding War-Relevant and All Flagged Sectors



Note. Cartel-member coefficient with 95% confidence intervals for each outcome, excluding the war-relevant industries in the sense of Kocka (1984) (the state-important and procurement-linked divisions together), and excluding every flagged sector at once. The sector flags are manually coded at the industry-division level and are approximate. The count in brackets after each row label is the number of firm-year observations in that sample.

Table E.6: Firm Outcomes with Industry- and District-by-Year Fixed Effects

	Earnings	Investment		Upgrading		Scale	
	Revenue	Reserves	Capital	Exports	Patents	Production	Employment
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Cartel Member	0.08*** (0.03)	0.22*** (0.03)	0.24*** (0.02)	0.06*** (0.01)	0.02*** (0.00)	0.06** (0.02)	0.06*** (0.01)
R ²	0.97	0.85	0.88	0.63	0.53	0.99	0.96
Observations	38,665	172,730	200,796	278,080	278,080	54,654	41,642
Firms	6,435	15,982	21,867	25,333	25,333	4,034	3,877
Years	51	51	51	52	52	52	52
Outcome def.	(log)	(log)	(log)	(0/1)	(0/1)	(log)	(log)
Outcome mean	13.95	11.16	13.43	0.07	0.05	15.49	6.41
Standard errors	Firm	Firm	Firm	Firm	Firm	Firm	Firm
Firm fixed effects	✓	✓	✓	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓	✓	✓	✓
Industry × year	✓	✓	✓	✓	✓	✓	✓
District × year	✓	✓	✓	✓	✓	✓	✓

Note. Two-way fixed-effects estimates of cartel membership on the four main outcomes, adding industry-by-year and district-by-year fixed effects to the firm and year fixed effects of Table 1. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

Table E.7: Firm Outcomes Excluding Policy-Exposed Sectors

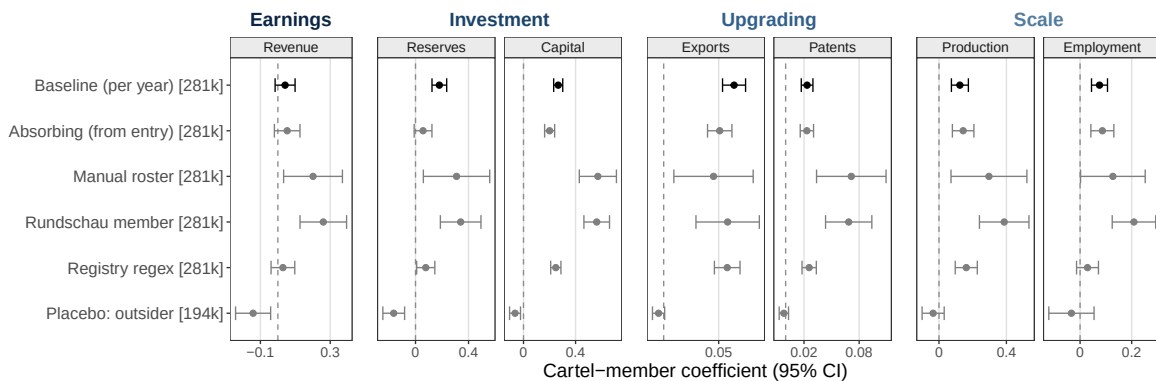
	Earnings	Investment		Upgrading		Scale	
	Revenue	Reserves	Capital	Exports	Patents	Production	Employment
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Cartel Member	-0.01 (0.04)	0.15*** (0.04)	0.24*** (0.02)	0.05*** (0.01)	0.01*** (0.00)	0.04 (0.03)	0.05* (0.03)
R ²	0.95	0.83	0.87	0.65	0.30	0.99	0.95
Observations	26,184	124,921	145,269	202,693	202,693	39,548	18,593
Firms	4,541	11,472	15,726	18,631	18,631	2,797	2,032
Years	51	51	51	52	52	52	51
Outcome def.	(log)	(log)	(log)	(0/1)	(0/1)	(log)	(log)
Outcome mean	13.66	11.02	13.27	0.06	0.01	14.51	5.95
Standard errors	Firm	Firm	Firm	Firm	Firm	Firm	Firm
Firm fixed effects	✓	✓	✓	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓	✓	✓	✓

Note. Two-way fixed-effects estimates of cartel membership on the four main outcomes, on the sample that drops every sector flagged as strategic, state-important, subject to compulsory cartels, or linked to government procurement. This is the all-flagged estimate of Appendix Figure E.8, shown in full; the war-relevant category of Kocka (1984) is a subset of these flags. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

E.3 Spillovers and Treatment Contamination

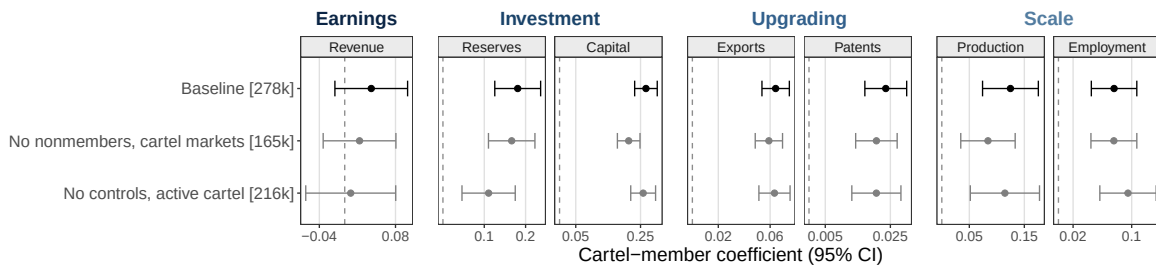
Cartel membership may be mismeasured, and nonmember firms in cartelized markets may themselves be affected by the cartel, contaminating the comparison group. Appendix Figure E.9 re-estimates the main specification under alternative treatment definitions: the absorbing post-entry indicator, each of the three membership sources separately, and a placebo that assigns never-member firms the first cartel year of their market. The estimates are positive and of comparable magnitude across definitions, and the placebo estimates are close to zero for patenting and exporting. Appendix Figure E.10 then drops nonmember firms in ever-cartelized markets, and separately drops control firm-years in market-years with an active cartel member. The estimates change little under either restriction.

Figure E.9: Firm Estimates under Alternative Treatment Definitions



Note. Cartel-member coefficient with 95% confidence intervals for each outcome under the treatment definitions listed on the vertical axis, each with firm and year fixed effects and standard errors clustered by firm. The absorbing definition switches on at cartel entry and stays on; the three source definitions record cartel membership from a manually collected roster, cartel-association member lists, and a registry-name search. The placebo restricts to never-member firms and switches on from the first year a cartel appears in the market of the firm, a NACE three-digit industry by district cell. The count in brackets after each row label is the number of firm-year observations in that sample.

Figure E.10: Firm Estimates Omitting In-Market Nonmembers



Note. Cartel-member coefficient with 95% confidence intervals for each outcome, dropping nonmember firms in markets that ever cartelized, and dropping control firm-years in market-years with an active cartel member. A market is a NACE three-digit industry by district cell. Standard errors are clustered by firm. The count in brackets after each row label is the number of firm-year observations in that sample.

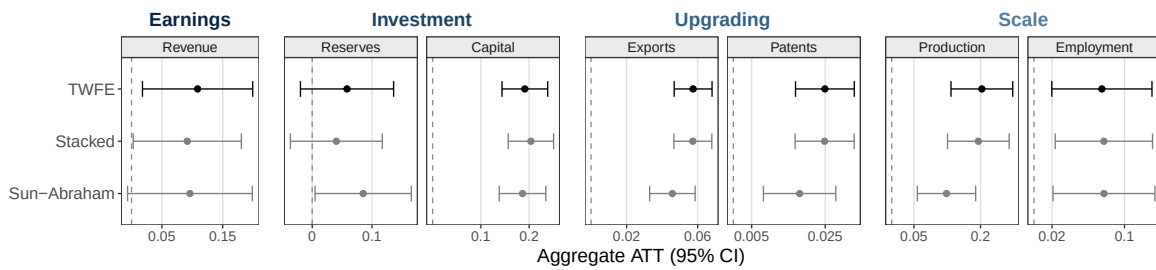
E.4 Further Sensitivity

This subsection varies the estimator, the sample, the influential units, and the inference.

E.4.1 Staggered Timing

Cartels formed in waves, so the two-way fixed-effects estimator can be biased when the effect varies across entry cohorts. Appendix Figure E.11 re-estimates the outcomes with heterogeneity-robust estimators under an absorbing treatment definition. Their aggregate estimates are close to the two-way fixed-effects estimate.

Figure E.11: Firm Estimates across DiD Estimators

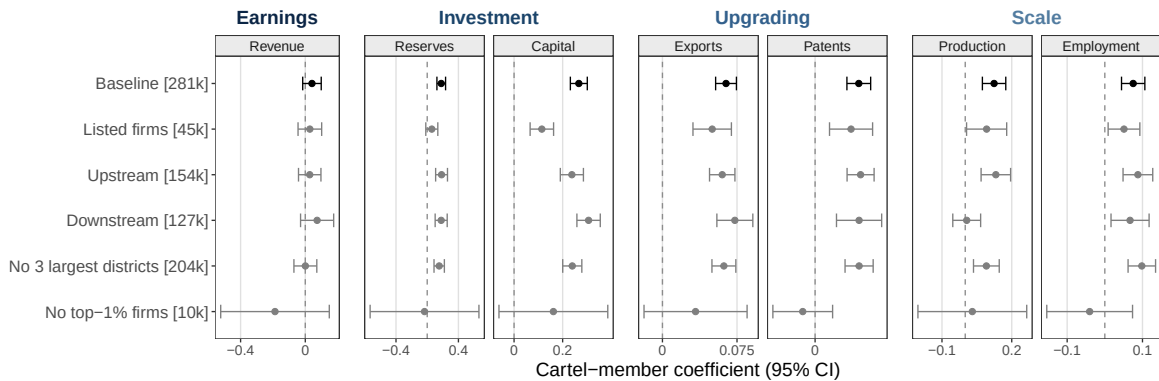


Note. Aggregate treatment effect with 95% confidence intervals for each outcome, estimated by two-way fixed effects and by the heterogeneity-robust estimators listed on the vertical axis, under an absorbing treatment definition. The Sun-Abraham estimator (Sun and Abraham, 2021) groups entry years into five-year cohorts.

E.4.2 Sample Composition

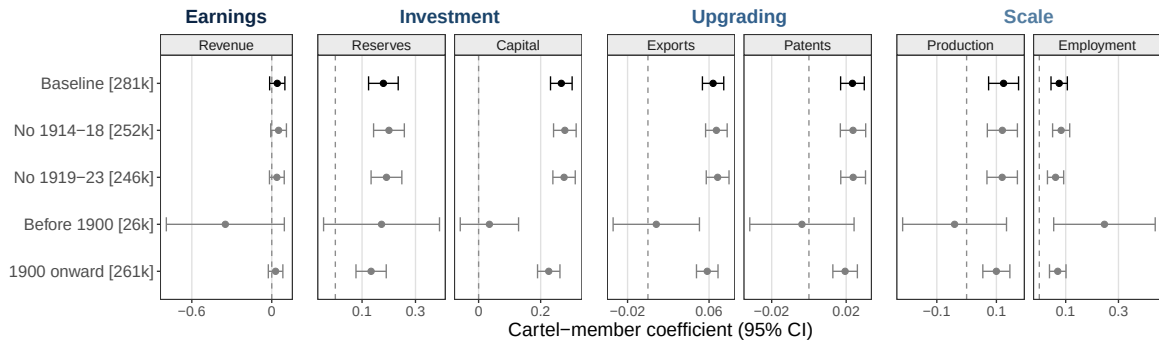
Appendix Figures E.12, E.13, and E.14 restrict the sample in turn to listed firms, to upstream and downstream sectors, and to sub-periods, and drop the largest districts, the largest firms, the war years, and the inflation years; they also separate firms with a single cartel spell from those with several, where a spell is a maximal run of consecutive cartel membership years. The largest-firm restriction uses the baseline-year size of each firm, so it is predetermined rather than a consequence of treatment. The estimates stay close to the baseline across these restrictions.

Figure E.12: Firm Estimates across Subsamples



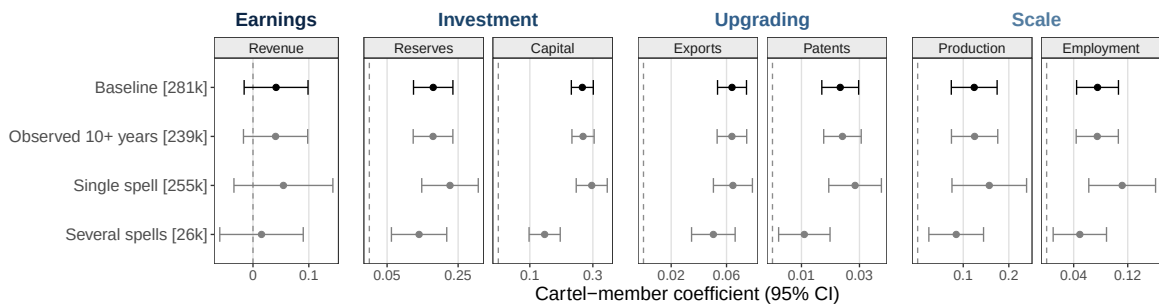
Note. Cartel-member coefficient with 95% confidence intervals for each outcome across the sample restrictions listed on the vertical axis, each with firm and year fixed effects and standard errors clustered by firm. The count in brackets after each row label is the number of firm-year observations in that sample.

Figure E.13: Firm Estimates across Sub-Periods



Note. Cartel-member coefficient with 95% confidence intervals for each outcome across the periods listed on the vertical axis, each with firm and year fixed effects and standard errors clustered by firm. The count in brackets after each row label is the number of firm-year observations in that sample.

Figure E.14: Firm Estimates by Firm History

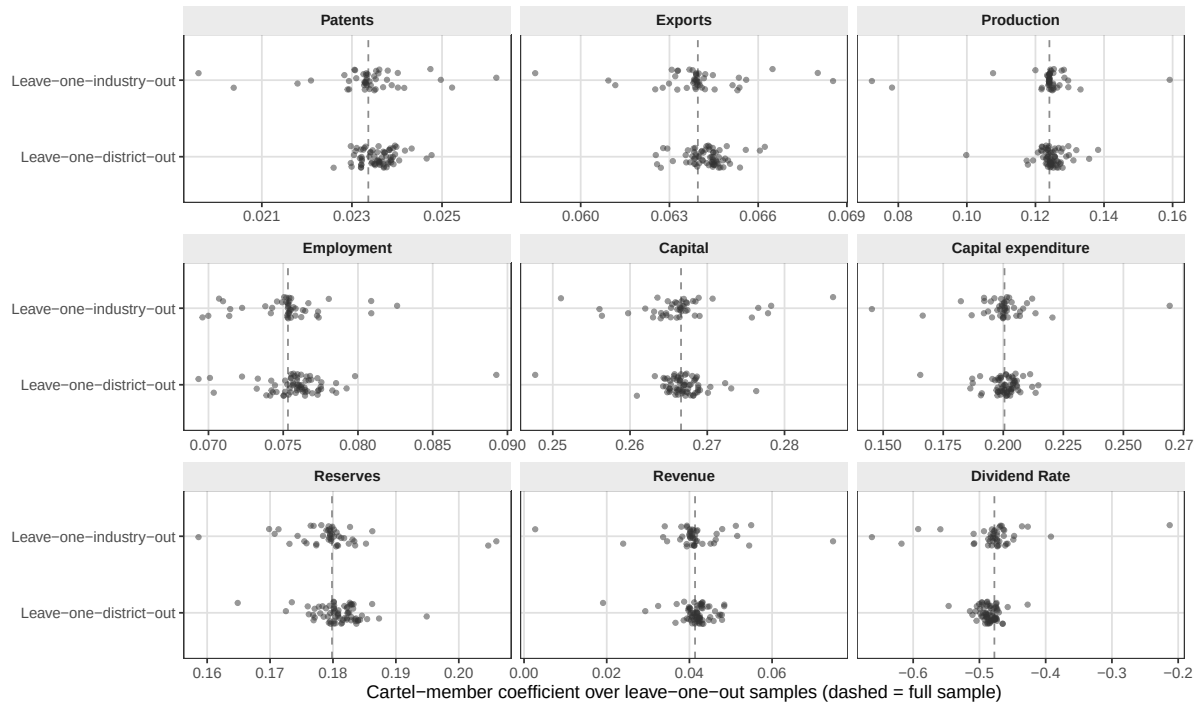


Note. Cartel-member coefficient with 95% confidence intervals for each outcome for firms observed at least ten years, firms with a single cartel spell, and firms with several spells, each with firm and year fixed effects and standard errors clustered by firm. A spell is a maximal run of consecutive cartel membership years. The count in brackets after each row label is the number of firm-year observations in that sample.

E.4.3 Influential Units

Appendix Figure E.15 omits one industry at a time and one district at a time. The spread of the leave-one-out estimates is narrow and centered on the full-sample estimate.

Figure E.15: Leave-One-Out Estimates

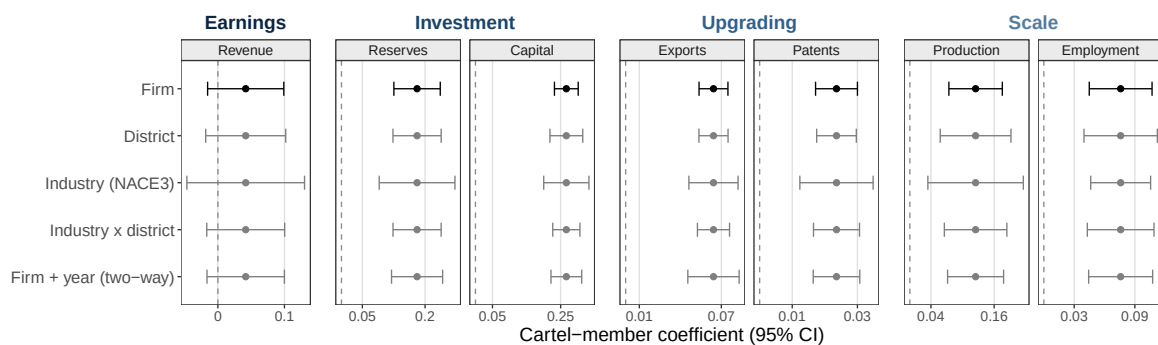


Note. Cartel-member coefficient for each outcome over samples that drop one two-digit industry at a time and one district at a time; the dashed line is the full-sample estimate. Each point is one omitted group.

E.4.4 Inference

Appendix Figure E.16 recomputes the standard errors under alternative clustering, from the firm to the industry-by-district market; the point estimate is unchanged and only the interval varies. We also run a placebo permutation test of the null hypothesis of no effect. In each of 200 draws we randomly permute the vector of firm cartel-entry years across firms, preserving the marginal distribution of entry timing; a permuted entry that falls outside the observed window of a firm leaves that firm a never-member firm in the draw. We refit the absorbing-treatment specification on each draw and record the coefficient, then compare the observed estimate to the resulting null distribution. Among the 200 draws, none produced an estimate as large as those observed for the densely observed outcomes, patenting and exporting.

Figure E.16: Inference under Alternative Clustering

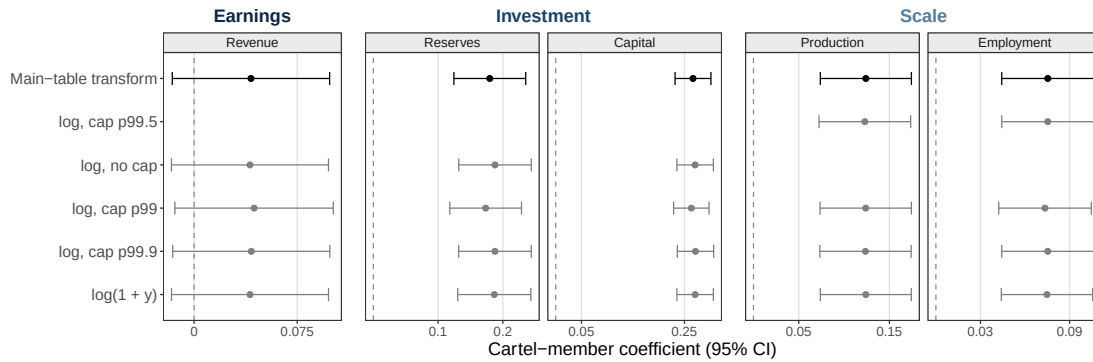


Note. Cartel-member coefficient for each outcome; the point estimate is fixed and the 95% confidence interval is recomputed under the clustering dimensions listed on the vertical axis. A market is a NACE three-digit industry by district cell.

E.5 Choice of Measure

Appendix Figure E.17 re-estimates each continuous outcome under alternative transforms: the logarithm after trimming values above the 99th, 99.5th, or 99.9th percentile; the logarithm without trimming; and $\log(1 + \max\{y, 0\})$; for the dividend rate, also its level after trimming at the 99.5th percentile. The baseline trims at the 99.5th percentile before taking logarithms; output and employment enter without trimming, and the dividend rate enters in percent of share capital. Signs are generally stable, but precision changes for some outcomes. Coefficient magnitudes are not comparable across transforms. The logarithm drops nonpositive values, while $\log(1 + \max\{y, 0\})$ sets them to zero.

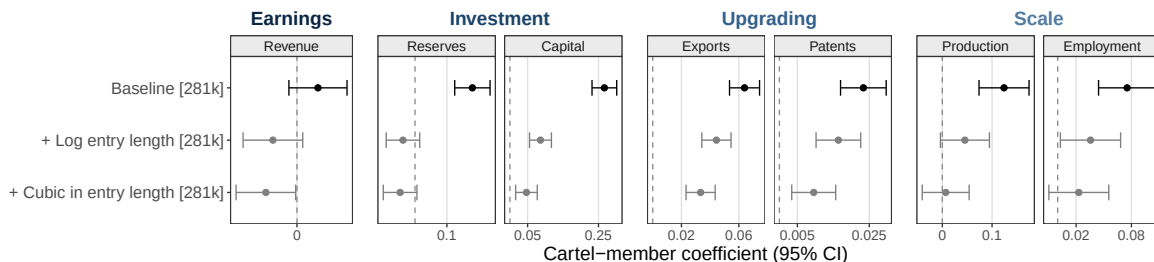
Figure E.17: Firm Estimates across Outcome Transforms



Note. Cartel-member coefficient with 95% confidence intervals for the continuous outcomes under the outcome transforms listed on the vertical axis. The baseline row is the transform of the main table for each outcome. Coefficients are not comparable in magnitude across transforms.

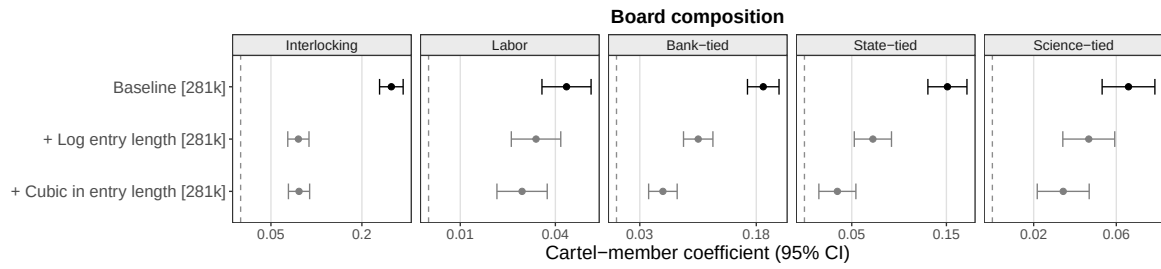
Appendix Figure E.18 adds the contemporaneous length of the firm's handbook entry to the two-way fixed-effects regression, in two functional forms (the logarithm of one plus the length, and a cubic polynomial in it), because a firm's entry lengthens once it becomes cartel-notable and a longer entry could mechanically report more of any count-based outcome. The coefficients attenuate but generally remain positive. Because entry length is itself affected by cartel membership, the control over-corrects, so the controlled estimates are a conservative lower bound rather than a point estimate.

Figure E.18: Firm Estimates Controlling for Handbook Entry Length



Note. Cartel-member coefficient with 95% confidence intervals for each outcome, adding the contemporaneous handbook entry length (the character length of the firm's operations abstract) to the firm and year fixed effects of the baseline, in the functional forms listed on the vertical axis. Appendix Figure E.19 reports the board-composition counts, the outcomes most exposed to reporting intensity. Because entry length is itself affected by cartel membership, the control over-corrects and the controlled estimates are a conservative lower bound. Standard errors are clustered by firm. The count in brackets after each row label is the number of firm-year observations in that sample.

Figure E.19: Board Composition Controlling for Handbook Entry Length



Note. Cartel-member coefficient with 95% confidence intervals for the board-composition counts, adding the contemporaneous handbook entry length to the firm and year fixed effects of the baseline, in the functional forms listed on the vertical axis, as in Appendix Figure E.18. Standard errors are clustered by firm. The count in brackets after each row label is the number of firm-year observations in that sample.

E.6 Mechanism Robustness

We check the financing and governance results of Section 5.3 in three ways: instrumented estimates, capital-intensity splits, and alternative measures of board composition.

Appendix Tables E.8 and E.9 report two-stage least squares estimates of equation (9) for the financing and board outcomes, with the specification of Table 2. For the financing outcomes, instrumented cartel membership is associated with higher investment, retained earnings, and profit, and with a higher dividend rate: the shift-share estimate is 3.66 percentage points and significant at the 5% level, while the within-firm estimate is negative. For the board outcomes, the shift-share estimate (Panel B) is positive and significant at the 1% level for employee representatives; the interlocking, bank-tied, and state-tied coefficients are imprecisely estimated. The employee-representative coefficient remains significant in Panels C to E, and the bank-tied coefficient is significant at the 10% level in Panel C.

Appendix Tables E.10 and E.11 repeat the capital-intensity split of Table 5 for the financing and board outcomes. For the financing outcomes, the interaction is positive and significant for retained earnings and not statistically distinguishable from zero for the others. For the board outcomes, the coefficients below the median remain positive and significant, and the interactions are small; only the employee-representative interaction is significant.

Appendix Tables E.12 and E.13 measure the board outcomes differently. In Appendix Table E.12, each outcome is the percentage of the board holding the tie: in years of cartel membership, the interlocking, employee-representative, and bank-tied shares are higher, while the state-tied share is unchanged. Appendix Table E.13 adds board size as a control to the count regressions of Table 4; all four coefficients remain positive and significant. Appendix Table E.14 reports the university-ties outcome — board members with a scientific or engineering title — separately from the governance ties; the coefficient is positive and significant at the 1% level.

Table E.8: Cartel Membership and Financing: Instrumental-Variable Estimates

	Payout	Investment
	Dividend Rate	Capital expenditure
	(1)	(2)
<i>Panel A: OLS</i>		
Cartel member	-0.75*	0.24**
	(0.42)	(0.11)
R ²	0.50	0.62
Observations	288,626	28,605
<i>Panel B: Shift-share instrument</i>		
Cartel member	3.66**	3.89**
	(1.77)	(1.72)
R ²	0.50	0.62
First-stage F	22.0	17.3
Observations	288,626	28,605
<i>Panel C: Ideal experiment (districts split by a law border)</i>		
Cartel member	7.48***	4.91**
	(1.36)	(2.00)
R ²	0.50	0.68
First-stage F	30.6	17.6
Observations	55,154	6,945
<i>Panel D: Recentered</i>		
Cartel member	3.70**	3.89**
	(1.77)	(1.72)
R ²	0.50	0.62
First-stage F	22.1	17.5
Observations	288,626	28,605
<i>Panel E: Recentered, reversals only</i>		
Cartel member	3.01	1.70
	(2.01)	(2.02)
R ²	0.50	0.62
First-stage F	12.3	6.6
Observations	288,626	28,605
Firms	20,768	5,887
Years	52	51
Outcome def.	(%)	(log)
Outcome mean	5.50	13.30
Standard errors	Industry	Industry
Sample	Dividend	Investment
Firms observed pre- and post-1897	3,928	686
Firm fixed effects	✓	✓
Year fixed effects	✓	✓

Note. As Table 2, for the financing outcomes of Table 3.

Table E.9: Cartel Membership and Board Composition: Instrumental-Variable Estimates

	Interlocking (1)	Labor (2)	Bank-Tied (3)	State-Tied (4)
<i>Panel A: OLS</i>				
Cartel member	0.18*** (0.02)	0.05*** (0.01)	0.16*** (0.02)	0.11*** (0.02)
R ²	0.73	0.32	0.70	0.71
Observations	280,930	280,930	280,930	280,930
<i>Panel B: Shift-share instrument</i>				
Cartel member	0.18 (0.26)	0.17*** (0.06)	0.23 (0.24)	0.01 (0.38)
R ²	0.73	0.31	0.70	0.70
First-stage F	28.1	28.1	28.1	28.1
Observations	280,930	280,930	280,930	280,930
<i>Panel C: Ideal experiment (districts split by a law border)</i>				
Cartel member	0.24 (0.19)	0.18*** (0.06)	0.60* (0.36)	0.72 (0.53)
R ²	0.73	0.32	0.70	0.72
First-stage F	18.1	18.1	18.1	18.1
Observations	54,084	54,084	54,084	54,084
<i>Panel D: Recentered</i>				
Cartel member	0.18 (0.26)	0.17*** (0.06)	0.23 (0.24)	0.01 (0.38)
R ²	0.73	0.31	0.70	0.70
First-stage F	28.3	28.3	28.3	28.3
Observations	280,930	280,930	280,930	280,930
<i>Panel E: Recentered, reversals only</i>				
Cartel member	0.15 (0.32)	0.18** (0.07)	0.22 (0.28)	-0.24 (0.41)
R ²	0.73	0.31	0.70	0.70
First-stage F	17.4	17.4	17.4	17.4
Observations	280,930	280,930	280,930	280,930
Firms	25,817	25,817	25,817	25,817
Years	52	52	52	52
Outcome def.	(log 1+x)	(log 1+x)	(log 1+x)	(log 1+x)
Outcome mean	1.30	0.03	0.44	0.45
Standard errors	Industry	Industry	Industry	Industry
Sample	Full	Full	Full	Full
Firms observed pre- and post-1897	831	831	831	831
Firm fixed effects	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓

Note. As Table 2, for the board outcomes of Table 4.

Table E.10: Cartel Membership, Payout, and Capital Expenditure, by Capital Intensity

	Payout	Investment
	Dividend Rate	Capital expenditure
	(1)	(2)
Cartel Member	-0.67** (0.27)	0.12 (0.12)
Cartel Member $\times$ Capital intensity	0.33 (0.33)	0.10 (0.13)
R ²	0.50	0.62
Observations	288,669	28,605
Firms	20,776	5,887
Years	52	51
Outcome def.	(%)	(log)
Outcome mean	5.50	13.30
Standard errors	Firm	Firm
Sample	Dividend	Investment
Firm fixed effects	✓	✓
Year fixed effects	✓	✓

Note. As Table 5, for the financing outcomes of Table 3.

Table E.11: Cartel Membership and Board Composition, by Capital Intensity

	Interlocking	Labor	Bank-Tied	State-Tied
	(1)	(2)	(3)	(4)
Cartel Member	0.26*** (0.02)	0.03*** (0.01)	0.20*** (0.02)	0.18*** (0.02)
Cartel Member $\times$ Capital intensity	-0.01 (0.02)	0.02** (0.01)	-0.02 (0.02)	-0.06** (0.02)
R ²	0.73	0.32	0.70	0.71
Observations	281,296	281,296	281,296	281,296
Firms	26,023	26,023	26,023	26,023
Years	52	52	52	52
Outcome def.	(log 1+x)	(log 1+x)	(log 1+x)	(log 1+x)
Outcome mean	1.30	0.03	0.44	0.45
Standard errors	Firm	Firm	Firm	Firm
Sample	Full	Full	Full	Full
Firm fixed effects	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓

Note. As Table 5, for the board outcomes of Table 4.

Table E.12: Cartel Membership and Board Composition, Share of Board

	Interlock Share (1)	Labor Share (2)	Bank Share (3)	State Share (4)
Cartel Member	3.50*** (0.35)	0.64*** (0.09)	1.53*** (0.37)	0.36 (0.40)
R ²	0.66	0.33	0.63	0.64
Observations	271,788	260,788	260,788	260,788
Firms	25,372	24,891	24,891	24,891
Years	52	52	52	52
Outcome def.	(%)	(%)	(%)	(%)
Outcome mean	45.52	0.62	15.61	16.03
Standard errors	Firm	Firm	Firm	Firm
Sample	Full	Full	Full	Full
Firm fixed effects	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓

Note. The outcomes are the percentage of the firm's board members (board and directorate for interlocks; supervisory board otherwise) holding the tie named in the column. Observations are at the firm-year level, with firm and year counts shown in the table. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

Table E.13: Cartel Membership and Board Composition, Controlling for Board Size

	Interlocking (1)	Labor (2)	Bank-Tied (3)	State-Tied (4)
Cartel Member	0.11*** (0.01)	0.03*** (0.00)	0.13*** (0.01)	0.08*** (0.01)
R ²	0.84	0.33	0.73	0.75
Observations	279,980	280,039	280,039	280,039
Firms	25,992	25,999	25,999	25,999
Years	52	52	52	52
Outcome def.	(log 1+x)	(log 1+x)	(log 1+x)	(log 1+x)
Outcome mean	1.30	0.03	0.44	0.45
Standard errors	Firm	Firm	Firm	Firm
Sample	Full	Full	Full	Full
Board size control	✓	✓	✓	✓
Firm fixed effects	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓

Note. The outcomes are the logarithm of one plus the number of board members holding the tie named in the column, with the logarithm of one plus the size of the relevant body (board and directorate for interlocks; supervisory board otherwise) added as a control. Observations are at the firm-year level, with firm and year counts shown in the table. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

Table E.14: Cartel Membership and University Ties

	Science-Tied (1)
Cartel Member	0.07*** (0.01)
R ²	0.55
Observations	281,296
Firms	26,023
Years	52
Outcome def.	(log 1+x)
Outcome mean	0.11
Standard errors	Firm
Sample	Full
Firm fixed effects	✓
Year fixed effects	✓

Note. Table presents results of estimating equation (9). The outcome is the number of supervisory board members with an engineering or academic title, as introduced in Section 4, as the logarithm of one plus the count. Observations are at the firm-year level; the numbers of firm-years, firms, and years are shown in the table. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

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