Coordination and Collusion in Industrial Development

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Abstract

Does coordination among firms impede industrial development by enabling collusion, or can it support development through joint investment? We study this question during Germany's rapid industrialization between 1882 and 1945, when the country caught up to the industrial frontier and cartels became legally enforceable, eventually organizing more than half of industrial output. Linking 2,374 cartel contracts to a panel of 30,793 joint-stock firms, their board members, input–output linkages, and inter-cartel agreements, we estimate the association between cartels and firm value, trade, and innovation. Our empirical strategy uses the staggered legalization of cartels through landmark court decisions, which drove much of the observed variation in adoption. Event studies show no pre-trends in outcomes prior to cartel formation, and we complement this approach with a shift-share instrument based on the applicability of court rulings. We find that cartel members outperformed comparable firms across all three outcome groups. Patterns across cartel types and industries are consistent with both investment and price coordination contributing to these gains. Higher markups are consistent with a relaxation of financial constraints, more so where external discipline was stronger or returns to investment were higher. Downstream distortions appear only partly mitigated through inter-cartel negotiation. At the aggregate level, we find no average decline in employment, and cartels were later repurposed for wartime mobilization. These results point to a model of delegated, coordination-based development in which gains in investment were not fully separable from downstream distortions and from an organizational infrastructure vulnerable to coercive uses.

Keywords: cartels; industrialization; firm coordination; investment; financial frictions
JEL Classification: L13, L14, L41, N43, N44, O14

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1 Introduction

In practice, many episodes of industrialization were accompanied by cartels and conglomerates, and these experiences underpin a long-standing policy debate between advocates of "bigness" and "smallness" in the economy (Brandeis, 1934; Draghi, 2024).

Industrialization often occurs in leaps and bounds. What drives such episodes of structural change? One view emphasizes coordination across firms: internalizing investment complementarities can stimulate growth (Rosenstein-Rodan, 1943; Murphy et al., 1989). This is consistent with the broader idea that contractual arrangements may help address externalities (Coase, 1960). At the same time, however, such arrangements may enable coordination on prices. This motivates restrictions on inter-firm contracting as a means of preventing collusion (Williamson, 1968).[1] Systematic evidence studying this trade-off between coordination and collusion in industrial development remains limited (Juhász and Steinwender, 2024).

We study Germany between 1882 and 1945. Within a few decades, the country moved from relative backwardness to the industrial frontier and mobilized resources for two world wars (Gerschenkron, 1962). Over the same period, cartels became widespread and legally enforceable, emerging as a defining feature of German industry (Winkler, 1974; Chandler, 1990).[2] Cartels varied substantially across industries, regions, and over time, while their legal status was clarified incrementally through court decisions. By 1930, 63% of firms listed on the Berlin Stock Exchange belonged to at least one cartel, up from 8% at the beginning of the period.

We assemble data linking 2,374 cartel contracts to a panel of 30,793 joint-stock firms, their board members, input–output ties, and inter-cartel agreements, together with a broad set of firm characteristics, a county–industry panel from six industrial censuses, and declassified records on firm-level involvement in the two world wars. To measure variation in the legal cost of cartel formation, we also digitize all 857 high-court decisions concerning cartels.

The analysis is organized around two questions. Part A studies the effects of cartels on member firms. Part B examines effects beyond member firms, focusing on spillovers, aggregate consequences, and wartime implications for the broader economy and the state. A framework connects

[1] Smith (1776) famously observed that "people of the same trade seldom meet together … but the conversation ends in a conspiracy against the public, or in some contrivance to raise prices."

[2] We 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).

Parts A and B.

In Part A, we estimate the association between cartel membership and three sets of firm-level outcomes: firm value (survival and stock prices), trade (exports and foreign direct investment), and innovation (patent quantity and quality). To address endogeneity in cartel formation, we combine two complementary approaches: first, staggered difference-in-differences based on the timing of membership, event studies that trace dynamics and test for pre-trends, rich controls for industry, region, and pre-treatment firm characteristics; and second, an instrumental-variable design that uses plausibly exogenous variation in the legal cost of cartel formation constructed from our digitized court decisions. Across specifications, cartel members were more likely to survive, had higher stock prices, exported more, undertook more foreign direct investment, and generated more and higher-quality patents than comparable firms in different markets.

Turning to mechanisms, cartel members accumulated more capital and became more vertically integrated than comparable firms. This suggests a role for increased investment activity. A stylized framework motivates three channels through which cartels might have increased investment. First, cartel agreements could directly coordinate investment, thus achieving economies of scale by internalizing externalities; consistent with this mechanism, the largest gains accrue in more sophisticated cartels that coordinated production in addition to prices. Second, price coordination may have relaxed financial frictions by raising operating margins, with the resulting leeway directed into investment. This requires the presence of an external disciplining institution. Consistent with this channel, we find that cartel members had deeper ties to banks, the state, and research institutions. Third, the gains are strongest where returns to investment were likely to be highest, namely in industries with high ex ante fixed costs, dual-use status, and greater pre-cartel exposure to international competition. Non-members in the same product market did not share these gains, suggesting that the relevant channel—whether in joint investment, discipline, or investment returns—operated primarily within cartels.

Part B examines spillovers beyond cartel members. Following the logic of Coase (1960), an externality generated by a within-industry cartel may be partly internalized when affected upstream or downstream industries can themselves contract. We operationalize this idea by decomposing a firm's exposure to upstream cartelization into a *negotiated* component, where upstream industries were connected by inter-cartel agreements, and a *non-negotiated* component. The distinction

is consequential: non-negotiated exposure depresses downstream performance, whereas negotiated exposure does not. At the aggregate level, county–industry cells with cartel presence show no systematic decline in employment, although entry and exit rates are compressed.

We then turn to cartel involvement in wartime production. Using 1913 cartel membership and cross-sectional measures of military contracting, wartime innovation, and World War II forced-labor involvement, we show that cartels formed part of the organizational core of war mobilization.

Taken together, the findings characterize cartels as part of a broader system of delegated, negotiation-based industrial organization that contemporaries described as "economic self-governance" (Liefmann, 1918).[3]

Our contribution is threefold. First, we provide long-run, firm-level microeconometric evidence on a central episode of catch-up industrialization. Relative to the historical literature on German cartels and development (Liefmann, 1905; Winkler, 1974; Chandler, 1990; Gerschenkron, 1962), we observe the evolution of cartel membership, firm performance, and inter-firm networks for nearly the universe of joint-stock firms. We also combine aggregate evidence to evaluate long-standing claims linking cartels to output growth in this setting (Kuznets, 1967).

Second, we add to the industrial policy literature (Murphy et al., 1989; Rodrik, 1996; Juhász and Steinwender, 2024; Lane, 2025) by studying a bottom-up, network-based implementation of industrial coordination alongside the more familiar top-down, state-led cases in Japan, Korea, and elsewhere (Johnson, 1982; Amsden, 1989). Within-industry cartel contracts internalize a scale-up externality; cross-industry agreements, in turn, internalize the spillover created by the first contract.

Third, we contribute to the literature on concentration, collusion, and innovation (Brandeis, 1934; Stigler, 1964; Aghion et al., 2005; Sugaya and Wolitzky, 2018; Igami and Sugaya, 2022; Kwon et al., 2024). Existing empirical work typically studies coordination within a single product market, often relying on cases revealed ex post. We instead observe a large number of legally enforceable cartels spanning upstream and downstream industries, linked by cross-sector agreements.

[3]Chandler (1990) refers to this system as "cooperative capitalism," while Winkler (1974) terms it "organized capitalism."

2 Institutional Context

This section introduces the empirical setting. Section 2.1 describes the German industrial catch-up. Section 2.2 introduces cartels and the variation we use for estimation. Section 2.3 describes three channels through which cartels might have affected member-firm investment. Section 2.4 concludes with inter-cartel negotiation and wartime embedding, which organize Part B.

2.1 From Late Developer to Industrial Frontier

Germany was "the last western power to enter the industrial field" (Kronstein, 1942),[4] importing manufactures into the 1860s before tariff and currency unification under the *Zollverein* permitted the first wave of joint-stock industry. By the eve of the First World War the gap had closed in almost every branch (Gerschenkron, 1962; Chandler, 1990): heavy industry, machinery, and electrical engineering had reached the international productive frontier, and chemicals had overtaken the United Kingdom and the United States outright. The scientific frontier moved with industry: German firms and their affiliated laboratories accounted for a disproportionate share of pre-1939 Nobel Prizes, particularly in chemistry (Appendix Figure A.1).

2.2 Cartels

A cartel was a contract among otherwise independent firms in the same industry to influence market conditions (Liefmann, 1905). Membership did not entail merger: firms retained their balance sheets, management, and operations, but agreed to constrain some subset of their conduct for a fixed term.

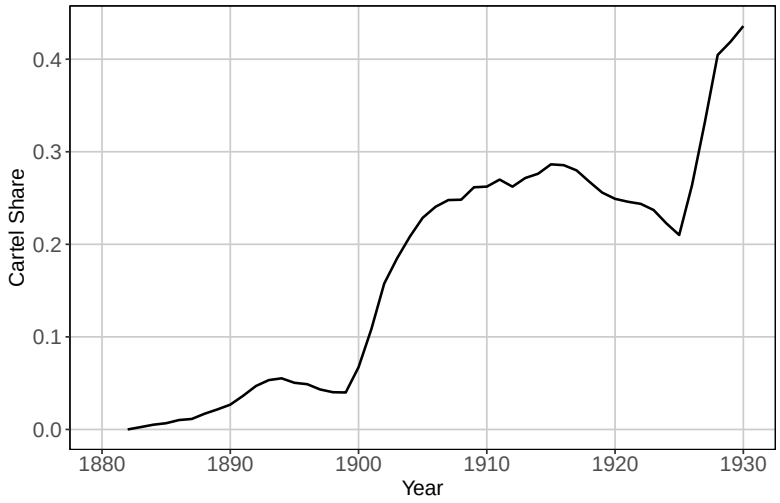
Cartel formation was uneven over time. Two features of the legal environment generated variation in cartel legal cost. Commercial law had been largely unified well before our period: a commercial code (the *ADHGB*) had been adopted across the German states by 1869 (Horn and Kocka, 1979). Cartel law was not homogeneous. It rested on general civil-law provisions whose enforceability was clarified case by case through Imperial Court rulings,[5] beginning with the 1897

[4] In 1876 the German industrialist Werner von Siemens described an economy still dependent on "foreign inventions and cheap labor" (Siemens, 1876).

[5] The legal environment was a salient business concern: the average issue of the *Kartell-Rundschau* devoted roughly 21% of its text body to legal questions surrounding cartelization.

Wood Pulp decision that permitted suit against a defecting cartel member to avoid "ruinous competition." The neighboring law of associations remained fragmented until the 1908 association law unified it, and the uncertain legal basis of cartels persisted into the 1920s, when a formal cartel court was established to set legal precedent. Figure 1 plots the resulting share of cartel members: it rises steeply from the late 1890s through World War I—contemporaries described the emergence of cartelization as striking "almost like lightning" (Schäffle, 1898, p. 467)—recovers during the interwar period, and peaks at 63% in 1930.

Figure 1: Share of Listed Firms with Cartel Membership, 1882–1945

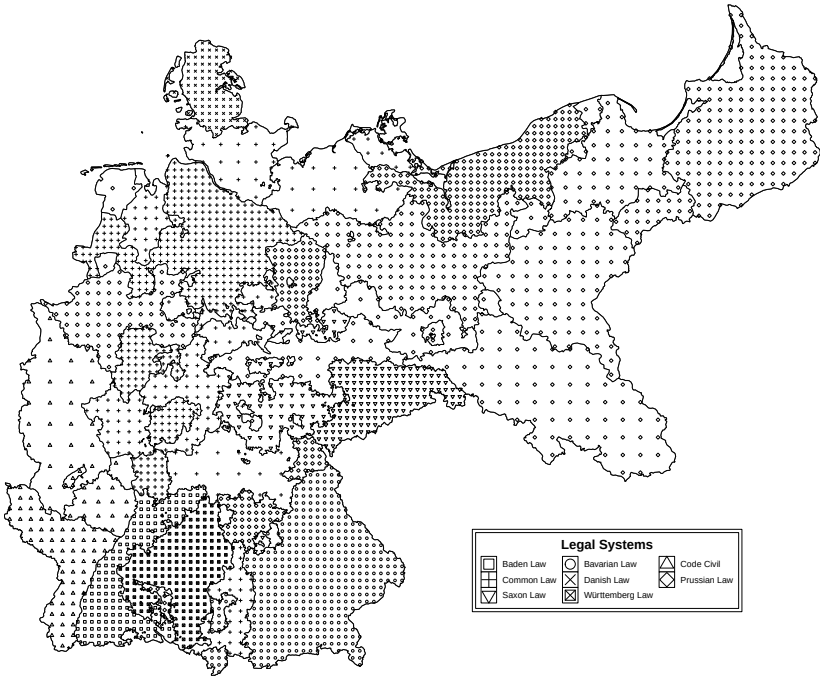


Note Figure plots the annual share of Berlin-listed joint-stock firms in our sample that belonged to at least one cartel (cartel membership (an indicator that firm i appears in the member list of at least one cartel in year t)), as introduced in Section 3. Vertical reference lines mark 1897 and 1923.

Cartel formation was also uneven across firms within years. Two additional features of the institutional setting generate the cross-sectional variation. First, the relevant market was local. The German Empire before 1914 was "a poorly integrated economy" (Wolf, 2009): trade districts within Germany were no better integrated than districts on opposite sides of the national border. We therefore treat the *county* as the relevant market; counties without active cartels in the same industry are a natural comparison group for those with cartels. Cross-county variation in cartel adoption within an industry is large. Appendix Figure A.2 shows the county geography alongside districts, states, and Chambers of Commerce. Second, whether a given Imperial Court precedent bound a particular cartel depended on the legal region of its parties. Imperial Germany contained

a patchwork of legal regions carried over from the historical principalities (Figure 2).

Figure 2: Legal Regions of Imperial Germany, 1895



Note Map displays the prevailing legal region of each Imperial German county in 1895, constructed from the 1896 *Rechtskarte* of German legal territories (Fischer, 1896). Shaded areas distinguish the legal regions carried over from the historical principalities.

2.3 What Cartels Did

Historical accounts suggest that contracts affected member-firm investment in three ways. We summarize each here and defer extensive case studies to Appendix B.

Investment coordination. The most direct case is when the investment itself is written into the contract. Joint research, capacity allocation, vertical integration, and shared sales infrastructure all appeared in cartel agreements. The chemical *Dreibund* of 1904—BASF, Bayer, and Agfa—pooled risk and retained earnings to finance the multi-year development of synthetic nitrogen fixation (Abelshauser et al., 2004).

Price-supported investment with external discipline. Where the contract did not directly govern investment, price coordination could still raise it indirectly. Price floors and quotas raised operating margins and therefore retained earnings. Three institutional pillars of the period channeled

that slack into investment: universal banks, whose representatives sat on member firms' supervisory boards and monitored capital deployment (Riesser, 1911); the state, through procurement, military demand, and supervisory-board appointments; and the system of research institutions—technical schools and universities—which credentialed the engineering workforce.

Price-supported investment without external discipline. Even absent an external disciplining institution, price coordination could suffice when the supported margin made joint upgrading privately rational. Cartels enforced their contracts internally through bond deposits and other civil-law instruments (Kestner, 1912), and contemporaries documented production-side improvements within cartel industries as byproducts of that internal discipline (Mullensiefen, 1926).

2.4 Beyond Members

A within-industry cartel imposed costs on downstream industries. The German cartel system contained an explicit mitigation device: *inter-cartel agreements* between upstream and downstream cartels—export-rebate systems, two-tier pricing, supply guarantees—that internalized the spillover at the contracting level. The Rhenish-Westphalian Coal Syndicate, for example, operated a formal export-rebate system with downstream steel cartels. The state's facilitating role in cross-cartel disputes crystallized around 1903, when the policy debate over *kontradiktorische Verhandlungen* ("contradictory negotiations" between affected parties) produced the operating norm (Schmoller, 1906); the 1904 *Deutscher Juristentag* placed inter-cartel coordination on the legal agenda as a question of aggregate consequence rather than contract law alone, concluding that "without the cartel a national industrial policy is not possible."

The same coordination organizations were available to the state during mobilization. Industry-level associations and supervisory boards became the channels through which procurement, capacity allocation, and forced-labor assignments were executed in both world wars. The post-1945 Allied decartelization campaign treated this organizational infrastructure as the object to be dismantled rather than as a symptom of an otherwise separate war economy (Crane, 2023).

Contemporary observers described the resulting arrangement as "economic self-governance" (Liefmann, 1918)—a system of delegated, negotiation-based industrial coordination in which cartels and their counterparties formed "a system of bilateral monopolies" along much of the value

chain (Jürgens, 1980).

3 Data

3.1 Firm-Level Panel

Units. Our analysis relies on four units. A *firm* (i) is a German joint-stock company. A *year* (t) is a calendar year between 1882 and 1945. An *industry* (s) is a two-digit NACE category; we classify firms at the four-digit NACE level throughout and refer to the two-digit aggregation as the firm's industry whenever we use the term "Industry". A *county* (c) is one of the 900 Imperial German counties as of 1882.

Sources. We construct an unbalanced firm-level dataset containing annual information on cartel membership, operations abstracts, balance sheets, and income statements using two investor manuals: *Saling's Börsen-Jahrbuch* (Hertslet et al., 1882–1933) and the *Handbuch der deutschen Aktiengesellschaften* (Thieme, 1897–1933).[6] These sources also provide individual-level information on executives and supervisory board members.

We digitize firm entries using image object detection combined with optical character recognition (OCR). For each entry, we separate the firm name, headquarters subtitle, and text body, harmonize firm names across years, and assign a four-digit NACE code based on the relevant operations abstract. Headquarters are geocoded and assigned to Imperial German counties.[7]

The resulting dataset covers 30,793 unique firms observed between 1882 and 1945, forming an unbalanced panel with 218,028 firm-year observations. Appendix D documents the digitization pipeline, discusses measurement issues associated with the 1923 hyperinflation and the subsequent Goldmark revaluation, and benchmarks the joint-stock sample against alternative sources.

[6] Most firms covered in *Saling's* are listed on the Berlin Stock Exchange, whereas the *Handbuch* includes all German joint-stock companies (*Aktiengesellschaften* and *Kommanditgesellschaften auf Aktien*). The main sample draws on both sources; results are robust to restricting the analysis to the consistent coverage of *Saling's*. We focus on manufacturing and exclude banks, insurance companies, and service-sector firms.

[7] We combine the boundaries of the 900 counties in 1882 (MPIDR and CGG, 2011) with historical coordinates of 76,000 cities and villages recorded in the *Meyers Orts- und Verkehrs-Lexikon des Deutschen Reichs* (https://www.meyersgaz.org).

3.2 Cartel Data

Cartel Membership. A firm is classified as treated in a given year if it belonged to at least one cartel. Because cartels were legal agreements and membership was considered relevant to investment, firm handbooks systematically reported cartel affiliations.[8]

Our procedure has two steps. First, we compile a complete list of cartel names from the *Kartell-Rundschau* (Tschierschky and Borger, 1903–1929), a bi-monthly industry journal reporting on cartel formations, dissolutions, membership changes, and negotiations; we manually digitize its annual tables of contents, which list all cartels active in each year. We supplement these with three cross-sectional surveys: Reichsministerium des Innern (1906) (based on government data collected since 1886), Silberberg (1910), and Wagenführ (1931). Second, we check whether each cartel name appears in the operations abstract of a firm-year via string lookup. The procedure identifies 4,872 firms belonging to 2,374 distinct cartels in at least one year, which form the time series in Figure 1. Appendix D details the digitization pipeline and reports representativeness checks against alternative cartel listings.

Cartel Organization. We complement the firm-level membership data with cartel-level attributes. From the primary sources, we record whether the cartel set prices, quantities, or both; whether it pooled sales through a joint agency; and its headquarters location. For a subset of cartels we access the full statute text. From the same sources, we compile 276 inter-cartel agreements, recording the two contracting cartels and the scope of the agreement.

Cartel Jurisdiction. As discussed in Section 2, cartel law was shaped by landmark court decisions—primarily by the Imperial Court before 1923 and by the Imperial Cartel Court thereafter. We digitize all 53,524 decisions of the Imperial Court (Reichsgericht, 1882–1933) and all 857 decisions of the Cartel Court (Reichsverband der Deutschen Industrie, 1924–1933) within our study period. To isolate cartel-relevant Imperial Court decisions, we first identify those cited in the secondary literature (Reichsministerium des Innern, 1906), then embed the preambles of all

[8]The reliability of the handbooks is underscored by their use in classified U.S. intelligence reports during World War II, which noted that "along with other information about stock corporations, the *Handbuch* was furnished with a statement concerning the principal price and market-regulating associations to which a corporation belonged" (OSS, 1944, p. vi).

decisions, select those close in embedding space, and manually assess relevance. For each of the resulting 857 relevant decisions, we record the industry of the affected cartel, the headquarters location of the parties, and whether the lower-court ruling was overturned. We map the prevailing legal regime of each county in 1882 using the 1896 map of German legal territories (Fischer, 1896) and construct county-level indicators for the applicable legal traditions; these enter the share component of the shift-share instrument in Section 4.4.

3.3 Outcome Data

We measure firm outcomes along three groups. For firm value, we record survival and, for listed firms, stock price. For trade, we construct an annual indicator for whether a firm was reported to engage in export activities,[9] and a parallel indicator for foreign direct investment. For innovation, we count patents filed by each firm in each year; we compile patent-level data for Germany from the *Reichspatentblatt* (Reichspatentamt, 1918–1933)[10] and match each patent to firms in our dataset using harmonized firm names. To link inventors to firms, we use the *Deutsche Biographie* (Hockerts and Lanzinner, 2025), which has entries on 818,044 individuals.

3.4 Linkage Data

Board Member Linkages. The joint-stock handbooks list board members and directors with their titles. Because state offices were encoded in titles (e.g., *Rat*, *Minister*), we construct an indicator for whether an individual held a state position and, aggregating to the firm level, record the number of board members with state ties in each year. We construct parallel indicators for bank- and engineer-affiliated board members, which enter the mechanism analysis in Section 5.

Input–Output Linkages. We measure input–output linkages between industries using the sector classification underlying our NACE codes, combined with a harmonized German industry input–output matrix. Let $InputShare_{ss'}$ denote the share of industry s' in the inputs of industry s. We combine these shares with the time-varying cartel share of each industry, $CartelShare_{s't}$ (the share of industry s' firms that belong to at least one cartel in year t), to construct cartel exposure

[9] Based on a keyword search for *Export*, *Ausfuhr*, and *Auslandsgeschäft* in the operations abstract.

[10] The *Reichspatentblatt* appeared weekly; we collate its annual volumes, OCR each issue, and extract patent titles, the names of granted firms, and inventors. Patents are dated by issuance year.

($\sum_{s'} InputShare_{ss'} \cdot CartelShare_{s't}$, summing the upstream cartel share over the input-output weights of the industry s of firm i). To separate negotiated from non-negotiated exposure, we intersect the industry pair (s, s') with the 276 inter-cartel agreements in our data, yielding the two components: negotiated cartel exposure (cartel exposure restricted to upstream industries s' that have an inter-cartel agreement with the industry of firm i) and non-negotiated cartel exposure (the complementary component of cartel exposure over industry pairs without an inter-cartel agreement).

3.5 Aggregate Data

We assemble an integrated county–industry panel from six German industrial censuses covering 1875, 1882, 1895, 1907, 1925, and 1933.[11] The panel records employment counts at the county–industry–census-year level and forms the basis of the aggregate analysis in Section 6.2. We additionally digitize regional trade statistics that reconstruct a trade matrix for 72 goods across 32 German regions and six export markets at five-year intervals between 1884 and 1934, which we link to our industry classification.

3.6 The War Economy

We construct four cross-sectional indicators capturing firm involvement in the wartime economies of World War I and II, based on declassified archival sources.

Wartime Economic Organization. From the *Files Concerning War Associations* of the Imperial Chancery (*BA R431/614*), we collect the names and firm affiliations of all directors serving on groups responsible for coordinating nationwide industrial production. Using these data, we construct an indicator equal to one if at least one director of a given firm headed an industry coordination board.

Military Procurement. Following World War I, the investor handbooks flagged firms involved in war supply production. We construct an indicator equal to one if a firm entry between 1918 and 1933 explicitly mentions such involvement.[12]

[11] We thank Ann-Christin Becker, Sebastian Braun, Richard Franke, and Felix Kersting for sharing the raw data of the 1895, 1907, and 1933 censuses.

[12] The relevant keyword is *Kriegslieferung*.

Military Innovation. As discussed in Section 2, wartime inventions related to state secrets were patented but not publicly disclosed. These patents were retroactively published by 1945. We consult the annual *Imperial Patent Office* publications post-1918 (Reichspatentamt, 1918–1933) to construct a count of the number of war-related inventions in World War I associated with a given firm.

Dual-Use Goods and Strategic Commodities. We identify strategic and dual-use goods and commodities using the European Commission's Strategic Trade Atlas (EC, 2025). We construct a binary indicator equal to one if a 4-digit NACE industry contains at least one strategic product. To build this measure, we harmonize the associated Harmonized System (HS) codes using the concordance from Liao et al. (2020), excluding all goods introduced after our sample period.

World War II: Forced Labor. Finally, we construct an indicator of firm participation in the forced labor system during World War II. We use the *Catalogue of Camps and Prisons in Germany and German-Occupied Territories 1939–1945* (Internationaler Suchdienst Arolsen, 1951). Our dataset records 2,600 firms, identified either by name or by known cover names.

3.7 Cross-Section Data

We supplement the firm-level panel with baseline county- and location-level characteristics that enter as controls in Sections 4–6.3. Summary statistics are reported in the appendix.

Physical Geography. At the county level, we measure area, city density, mean elevation, terrain ruggedness (European Environment Agency, 2013), and agricultural suitability (Fischer et al., 2021). At the location level, we compute distances to the coastline and to the nearest navigable river (Kunz, 1999) and record latitude and longitude.

Economic Geography. At the county level, we digitize the 1882 German industrial census to obtain employment counts. We record the number of steam engines in 1882 from Gieseler (2025) and aggregate the number of bankruptcies between 1879 and 1882 using Kling (2025). At the location level, we geocode 83 technical schools, identify 275 universities, and record 184 Chambers of Commerce, all measured in 1882, and digitize the railway network in the same year. For each location,

we compute the distance to the nearest technical school, university, Chamber of Commerce, and railway line.

Political Geography. For each county in 1882, we record its governing district and state. We construct indicators for whether the county belonged to Prussia—the largest state in Imperial Germany—and whether it formed part of the North German Confederation, the political alliance preceding unification. For each location, we compute distances to district, state, and national borders, as well as distances to the respective district, state, and national capitals.

4 Member Firms

This section addresses Part A: how cartel membership affected member firms along three outcome groups—firm value (survival, stock price), trade (exporter status, foreign direct investment), and innovation (patent quantity and quality). After laying out the empirical strategy, we report predictors of cartel formation, the main difference-in-differences and event-study estimates, robustness checks, and the instrumental-variable results.

4.1 Empirical Strategy

The central identification concern is that unobserved factors may jointly determine cartel participation and firm outcomes. Our approach addresses this concern through a combination of difference-in-differences estimators, dynamic specifications, rich controls, and an instrumental-variables design.

Difference-in-Differences. Our starting point is a staggered-adoption difference-in-differences (DiD) specification. We implement the estimator of Sun and Abraham (2021), which is robust to heterogeneous treatment timing and treatment-effect heterogeneity. The results remain stable across alternative estimators (Appendix E). Our baseline regression equation is

$$FirmOutcome_{it} = \beta\, Treated_{it} + \alpha_i + \alpha_t + \varepsilon_{it}. \tag{1}$$

$FirmOutcome_{it}$ denotes one of an indicator of firm i being active in year t, the inverse hyperbolic sine of the stock price of firm i in year t, an indicator of firm i exporter status in year t, an indicator of firm i FDI status in year t, the inverse hyperbolic sine of the number of patents filed by firm i in year t, or the CPC breadth of patents filed by firm i in year t. The variable $Treated_{it}$ is an indicator of whether firm i is a member of any cartel in year t. The fixed effects α_i and α_t absorb time-invariant firm characteristics and common time shocks, respectively. Standard errors are clustered at the firm level.

Event Studies. The identifying assumption of equation (1) is that, absent treatment, treated and untreated firms would have followed parallel outcome trajectories. The historical evidence in Section 2.2 is consistent with this assumption: the initial emergence of cartels was largely unanticipated, and cross-regional differences in adoption reflected idiosyncratic local conditions. To assess pre-trends and trace dynamics, we estimate an event study,

$$FirmOutcome_{it} = \sum_{\tau=-25}^{25} \beta_\tau \mathbf{1}(RelativeTime_{it} = \tau) + \alpha_i + \alpha_t + \varepsilon_{it}, \tag{2}$$

where $RelativeTime_{it}$ measures the number of years relative to the year in which a firm first became a cartel member (binarized to five-year intervals). The omitted category is $\tau = -1$. The remaining variables are as in equation (1).

Instrumental Variable: Court Decisions. Any remaining confounder would need to vary across firms and over time, coincide closely with the onset of cartel membership, generate a discrete and persistent change in outcomes, and not be absorbed by fixed effects and covariates. To probe for such a confounder, we use plausibly exogenous changes in the legal environment surrounding cartels. Landmark court decisions provide the shift for a shift-share instrumental variable (Bartik, 1991), described formally in Section 4.4.

Robustness. We address remaining concerns in four ways. First, we augment equation (1) with industry-by-year, county-by-year, bank-by-year, and initial-size-decile-by-year fixed effects, or with firm-specific linear trends, and interact the full set of baseline firm, political, geographic, and

economic characteristics from Section 3.7 with year indicators.[13] Second, we vary the definition of the market by replacing the within-industry, across-county comparison with within-industry comparisons across districts, states, or Chambers of Commerce (Appendix Figure A.2). Third, we drop NACE codes whose goods are easily tradable across counties, restricting the comparison to industries for which the county is closest to a single product market. Fourth, we repeat the analysis on more restrictive samples: early treatment adopters, firms initially traded in Berlin, and treatment–control pairs constructed via propensity-score matching.

4.2 Predictors of Cartel Membership

Before estimating the association between cartel membership and firm outcomes, we ask which firm and county characteristics predict cartel formation. We regress $Treated_{it}$ on the baseline firm, county, political, and legal covariates of Section 3.7. Table 1 reports the results.

Two caveats shape the interpretation of these estimates. First, any predictive power that baseline covariates have for cartel formation is absorbed by the fixed-effects structure used throughout Sections 4.3–6.3: firm, industry, and county fixed effects absorb cross-sectional differences in the propensity to cartelize, so the residual variation identifying the treatment effect is not driven by these predictors. Second, the dynamic variation in cartel formation is dominated by the sequence of landmark court decisions discussed in Section 2.2: once a precedent clarifies the enforceability of a given contract form, observed cartel formation responds more strongly to the legal shock than to pre-existing firm fundamentals. We therefore treat the predictor regression as descriptive, documenting the observable correlates of cartel status, and leave causal interpretation to the event-study, controlled, and instrumental-variable specifications below.

4.3 Difference-in-Differences and Event Studies

Table 2 reports estimates of equation (1) for the six firm-level outcomes in the three outcome groups: an indicator of firm i being active in year t and the inverse hyperbolic sine of the stock

[13] Covariates are firm age, initial traded status and firm size, indicators of whether a firm's headquarters were in a county that belonged to Prussia or the North German Confederation, distances to district, state, and national borders, as well as distances to the respective district, state, and national capitals; county area, city density, mean elevation, terrain ruggedness, and agricultural suitability; distances to the coastline and to the nearest navigable river; latitude and longitude; 1882 county-level employment; the number of steam engines in 1882 and the number of bankruptcies between 1879 and 1882 in a county; and the distance to the nearest technical school, university, Chamber of Commerce, and railway line.

Table 1: Predictors of Cartel Membership

Note Table reports a regression of an indicator of whether firm i is a member of any cartel in year t on initial firm, county, and legal characteristics introduced in Section 3.7. Observations are at the level of a firm-year. The number of firm-years and firms in each sample is indicated in the table. Covariates are firm age, initial traded status and firm size, indicators of whether a firm's headquarters were in a county that belonged to Prussia or the North German Confederation, distances to district, state, and national borders, as well as distances to the respective district, state, and national capitals; county area, city density, mean elevation, terrain ruggedness, and agricultural suitability; distances to the coastline and to the nearest navigable river; latitude and longitude; 1882 county-level employment; the number of steam engines in 1882 and the number of bankruptcies between 1879 and 1882 in a county; and the distance to the nearest technical school, university, Chamber of Commerce, and railway line. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

price of firm i in year t for firm value; an indicator of firm i exporter status in year t and an indicator of firm i FDI status in year t for trade; and the inverse hyperbolic sine of the number of patents filed by firm i in year t and the CPC breadth of patents filed by firm i in year t for innovation.

The treatment, an indicator of whether firm i is a member of any cartel in year t, is associated with an increase in an indicator of firm i being active in year t of 0.02 (clustered standard error: 0.01) and in the inverse hyperbolic sine of the stock price of firm i in year t of 0.05 (0.01) on the firm-value margin; an increase in an indicator of firm i exporter status in year t of 0.03 (0.01) and in an indicator of firm i FDI status in year t of 0.03 (0.01) on the trade margin; and an increase in the inverse hyperbolic sine of the number of patents filed by firm i in year t of 0.03 (0.01) and in the CPC breadth of patents filed by firm i in year t of 0.03 (0.01) on the innovation margin.

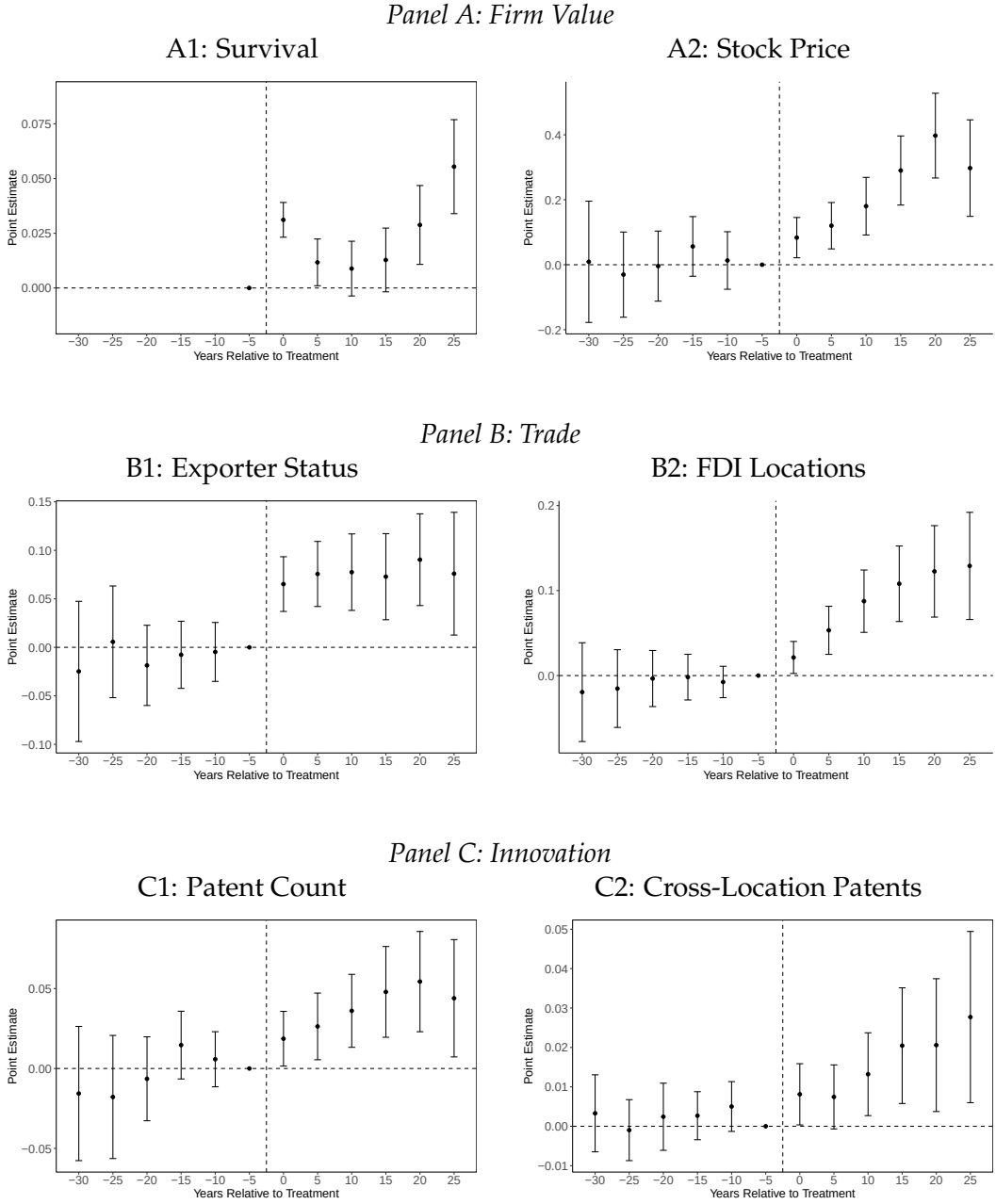
Figure 3 reports estimates of equation (2) for the three outcome groups. Within each panel, The pre-treatment coefficients are statistically insignificant and close to zero, and The post-treatment coefficients are all statistically significant and positive.

These estimates suggest that cartel membership was associated with improved member-firm performance across firm value, trade, and innovation. Appendix E assesses the robustness of the results in Table 2 and Figure 3.

4.4 Instrumental Variable: Court Decisions

Firms inferred the feasibility of cartel formation from legal precedent. We capture this using a shift-share instrument. The shift is the timing of cartel-relevant court decisions (Section 2.2); the share is whether a given ruling applied to the legal region of firm i. For each decision, we record the first and final ruling years of the underlying dispute, as well as the legal regions involved, and use these inputs to construct the inverse hyperbolic sine of accumulated count of landmark court decisions

Figure 3: Cartels and Firm Outcomes (Event Studies)



Note Figure presents results of estimating equation (2), with 95% confidence intervals. Observations are at the level of a firm-year, with the number of firm-years and firms in each sample indicated in Table 2. The dependent variables are in Panel A (A1) an indicator of firm i being active in year t and (A2) the inverse hyperbolic sine of the stock price of firm i in year t; in Panel B (B1) an indicator of firm i exporter status in year t and (B2) an indicator of firm i FDI status in year t; in Panel C (C1) the inverse hyperbolic sine of the number of patents filed by firm i in year t and (C2) the CPC breadth of patents filed by firm i in year t; as introduced in Section 3. The treatment is the number of years relative to the year in which a firm first became a cartel member (binarized to five-year intervals). The omitted category is $\tau = -1$. Firm and year fixed effects are included. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

Table 2: Cartels and Firm Outcomes

	Firm Value		Trade		Innovation	
	Survival	Stock Price	Exporter	FDI	Patents	Breakthrough
	(1)	(2)	(3)	(4)	(5)	(6)
Cartel Member	0.04***	0.06**	0.10***	0.03***	0.03***	0.010***
	(0.004)	(0.03)	(0.01)	(0.01)	(0.007)	(0.003)
Observations	43,344	34,057	43,344	43,344	43,344	43,344
R^2	0.32	0.71	0.43	0.82	0.56	0.32
Firms	2,890	2,046	2,890	2,890	2,890	2,890
Years	52	51	52	52	52	52
Outcome Mean	0.95	5.67	0.34	0.24	0.11	0.01
Cluster	Firm	Firm	Firm	Firm	Firm	Firm
Firm fixed effects	✓	✓	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓	✓	✓

Note Table presents results of estimating equation (1). Observations are at the level of a firm-year. The number of firm-years and firms in each sample is indicated in the table. The dependent variables are (1) an indicator of firm i being active in year t, (2) the inverse hyperbolic sine of the stock price of firm i in year t, (3) an indicator of firm i exporter status in year t, (4) an indicator of firm i FDI status in year t, (5) the inverse hyperbolic sine of the number of patents filed by firm i in year t, and (6) the CPC breadth of patents filed by firm i in year t, as introduced in Section 3. The treatment is an indicator of whether firm i is a member of any cartel in year t. Firm and year fixed effects are included in all columns. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

that clarified the enforceability of cartel contracts in the legal region of firm i up to year t, omitting any decision in the same industry and district as firm i.. To address non-random decision timing, we re-center the instrument following Borusyak and Hull (2023), drawing alternative decision years from a uniform distribution between the first and final ruling years.

Table 3 presents two-stage least-squares estimates of equation (1). Across the six outcomes—survival, stock price, exporter status, foreign direct investment, patent quantity, and patent quality—the IV estimates are of similar sign and magnitude to the difference-in-differences estimates in Table 2.

The instrumental-variable estimates indicate that the member-firm gains are unlikely to be driven by omitted factors that covary with both cartel formation and firm outcomes without also moving with the arrival of legal precedent.

Table 3: Cartels and Firm Outcomes (Instrumental Variable)

	Firm Value		Trade		Innovation	
	Survival	Stock Price	Exporter	FDI	Patents	Breakthrough
	(1)	(2)	(3)	(4)	(5)	(6)
Cartel Member	-0.007	1.2***	0.31***	0.22**	0.21***	0.008
	(0.03)	(0.22)	(0.10)	(0.10)	(0.05)	(0.01)
Observations	40,974	32,828	40,974	40,974	40,974	40,974
R^2	0.29	0.72	0.42	0.81	0.56	0.32
IV	✓	✓	✓	✓	✓	✓
Firms	2,890	2,046	2,890	2,890	2,890	2,890
Years	52	51	52	52	52	52
Outcome Mean	0.95	5.67	0.34	0.24	0.11	0.01
Cluster	Firm	Firm	Firm	Firm	Firm	Firm
Firm fixed effects	✓	✓	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓	✓	✓

Note Table presents results of estimating equation (1), estimated by two-stage least squares. Observations are at the level of a firm-year. The number of firm-years and firms in each sample is indicated in the table. The dependent variables are (1) an indicator of firm i being active in year t, (2) the inverse hyperbolic sine of the stock price of firm i in year t, (3) an indicator of firm i exporter status in year t, (4) an indicator of firm i FDI status in year t, (5) the inverse hyperbolic sine of the number of patents filed by firm i in year t, and (6) the CPC breadth of patents filed by firm i in year t, as introduced in Section 3. The treatment is an indicator of whether firm i is a member of any cartel in year t. The instrumental variable is the inverse hyperbolic sine of accumulated count of landmark court decisions that clarified the enforceability of cartel contracts in the legal region of firm i up to year t, omitting any decision in the same industry and district as firm i.. Firm and year fixed effects are included. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

5 Mechanism: Investment

The member-firm gains documented in Section 4 are consistent with several mechanisms. We argue that the primary mechanism is investment: cartel members accumulated more capital and integrated more vertically than comparable non-members, and the gains in firm value, trade, and innovation followed. On this reading, price coordination operated as an instrument for investment rather than as the source of the gain by itself.

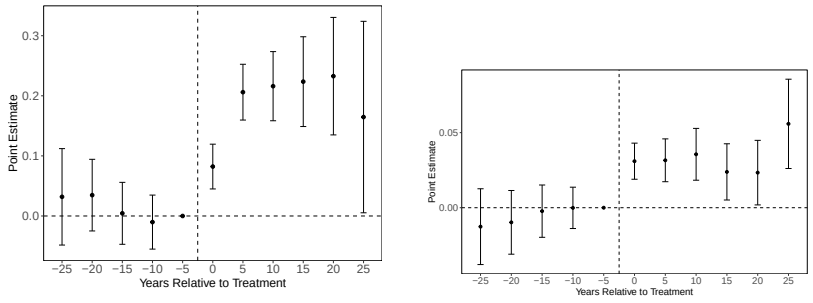
5.1 Cartels and Investment

The first result is direct. Figure 4 reports event-study estimates of cartel formation on two firm-level investment outcomes. Panel A shows that the inverse hyperbolic sine of total capital of firm i in year t rises around treatment by 0.08 (clustered standard error: 0.02), with no discernible pre-trend and a persistent post-treatment level shift. Panel B reports the parallel estimate for an

indicator of vertical integration of firm i in year t: vertical integration rises around treatment by 0.02 (0.01). Panel C is reserved as a placeholder for a forthcoming technology-investment outcome (e.g., investment rate, bond issuance, plant count). Taken together, the panels indicate that cartel membership moved member firms toward a higher capital stock and a longer supply chain—the two margins of investment we can currently measure in the firm-level panel.

Figure 4: Cartels and Investment (Event Studies)

A: Capital Investment B: Vertical Integration C: Technology Investment



[placeholder]

Note Figure presents results of estimating equation (2), with 95% confidence intervals. Observations are at the level of a firm-year. The dependent variables are (A) the inverse hyperbolic sine of total capital of firm i in year t and (B) an indicator of vertical integration of firm i in year t; Panel C is a placeholder for a forthcoming technology-investment outcome. The treatment is the number of years relative to the year in which a firm first became a cartel member (binarized to five-year intervals). The omitted category is $\tau = -1$. Firm and year fixed effects are included. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

5.2 Three Channels

A stylized framework motivates three channels through which cartels could raise member-firm investment. First, cartel agreements could directly coordinate investment—joint capacity, joint R&D, vertical integration—so that the cartel contract itself specifies the investment. Second, price coordination may have relaxed financial frictions by raising operating margins, with the resulting slack directed into investment by an external disciplining institution outside the contract. Third, even without external discipline, the supported operating margin could be high enough that joint upgrading is the privately rational resolution of an underlying coordination problem; in that case, the gains should be strongest in industries where returns to investment are highest. Appendix C formalizes each channel in a stylized two-stage duopoly. We address each in turn and then return to the role of scale.

5.3 Direct Investment Coordination

Cartels differed in contractual scope. Some set prices only; others coordinated quantities, R&D, and sales infrastructure in addition to prices. The direct prediction is that the broader the contracting scope, the larger the member-firm gain. Table 4 reports the test: we interact $Treated_{it}$ with indicators for cartel sophistication and re-estimate equation (1). Price-only cartels deliver substantially smaller and generally insignificant coefficients; cartels that also coordinate quantities and investment account for most of the member-firm gain. This pattern is consistent with direct coordination. Appendix B illustrates the upper end of cartel sophistication—the chemical *Dreibund* that financed synthetic nitrogen fixation.

Table 4: Member-Firm Outcomes by Cartel Type

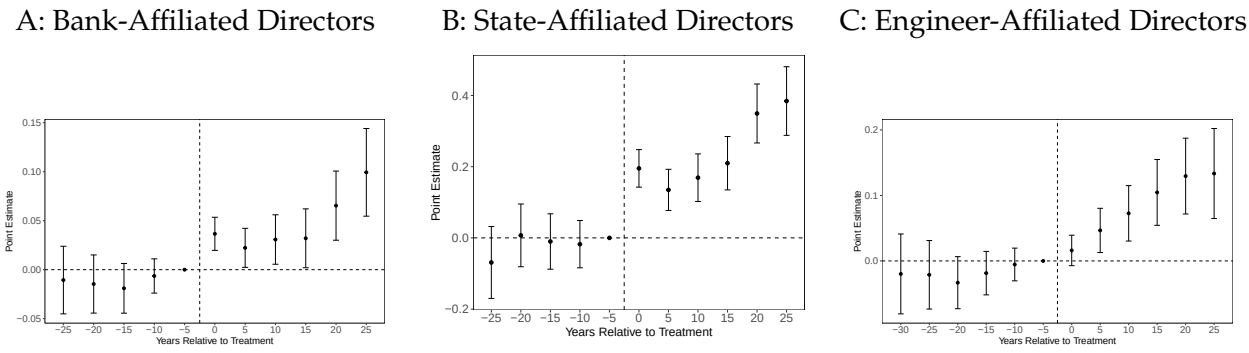
	Firm Value		Trade		Innovation	
	Survival	Stock Price	Exporter	FDI	Patents	Breakthrough
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Cartel complexity						
Cartel Member	0.04***	0.02	0.07***	0.01	0.03***	0.005
	(0.005)	(0.03)	(0.01)	(0.01)	(0.008)	(0.003)
Cartel Member × Complex Cartel	-0.002	0.10**	0.05***	0.04**	0.01	0.01**
	(0.006)	(0.04)	(0.02)	(0.02)	(0.01)	(0.006)
R^2	0.32	0.71	0.43	0.82	0.56	0.32
Panel B: Forced cartel						
Cartel Member	0.03***	0.08**	0.06***	0.03**	0.02***	0.006**
	(0.005)	(0.03)	(0.01)	(0.01)	(0.007)	(0.003)
Cartel Member × Forced Cartel	0.001	-0.01	0.004	0.003	-0.002	0.001
	(0.006)	(0.04)	(0.02)	(0.02)	(0.01)	(0.006)
Observations	43,344	34,057	43,344	43,344	43,344	43,344
R^2	0.31	0.70	0.42	0.81	0.55	0.31
Firms	2,890	2,046	2,890	2,890	2,890	2,890
Years	52	51	52	52	52	52
Outcome Mean	0.95	5.67	0.34	0.24	0.11	0.01
Cluster	Firm	Firm	Firm	Firm	Firm	Firm
Firm fixed effects	✓	✓	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓	✓	✓

Note Table presents results of estimating equation (1), with an indicator of whether firm i is a member of any cartel in year t interacted with cartel-type indicators: price-only, quantity-only, price-and-quantity, and forced cartels. Observations are at the level of a firm-year. The number of firm-years and firms in each sample is indicated in the table. Firm-level outcomes are an indicator of firm i being active in year t, the inverse hyperbolic sine of the stock price of firm i in year t, an indicator of firm i exporter status in year t, an indicator of firm i FDI status in year t, the inverse hyperbolic sine of the number of patents filed by firm i in year t, and the CPC breadth of patents filed by firm i in year t. Firm and year fixed effects are included. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

5.4 Price Coordination Paired with External Discipline

The second channel requires that price-induced retained earnings be directed into investment by an outside institution. Three institutional pillars of the period are candidates. Universal banks sat on supervisory boards and monitored capital deployment. The state backed industrial expansion through procurement, military demand, and supervisory-board appointments. Research institutions—the contemporary system of technical schools and universities—credentialed engineers and supplied trained managers. Figure 5 reports event-study estimates of cartel formation on the corresponding board-composition measures. Each measure rises around treatment, with no pre-trend.[14]

Figure 5: Cartels and Board Composition (Event Studies)



Note Figure presents results of estimating equation (2), with 95% confidence intervals. Observations are at the level of a firm-year. The dependent variables are (A) an indicator of firm i having a bank-affiliated board member in year t, (B) an indicator of firm i having a state-affiliated board member in year t, and (C) the inverse hyperbolic sine of the number of engineer-affiliated board members of firm i in year t. The treatment is the number of years relative to the year in which a firm first became a cartel member (binarized to five-year intervals). The omitted category is $\tau = -1$. Firm and year fixed effects are included. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

We interpret Figure 5 as evidence that cartel members deepened the institutional ties through which retained earnings were historically channeled into investment. Whether this channel generalizes to other settings depends on the existence of comparable disciplining institutions. That is a strong condition: it links naturally to the wartime embedding in Part B, but it also limits the broader policy reading of the result.

[14] We treat engineer-affiliated directors as a measure of the firm's tie to the system of research institutions; this conflates the disciplining role of those institutions with firm-level human capital and should be read accordingly.

5.5 Returns to Investment

The third channel does not require an external disciplining institution. In the framework of Appendix C, price coordination admits a high-investment equilibrium when the per-firm operating gain at the supported price is large enough to cover the investment cost. The cartel response should therefore be strongest in industries where returns to investment are highest. Table 5 interacts $Treated_{it}$ with three ex ante proxies for returns to investment: *upstreamness* (a proxy for fixed-cost intensity), *dual-use industry status* (a proxy for state procurement and military demand), and *1880s foreign-patenting intensity* (a proxy for export-market access). Each interaction has the predicted sign, and the response is concentrated in the high-return end of each distribution. We treat this pattern as suggestive rather than definitive: the proxies are coarse, and a tighter measure of returns to investment is the natural next step for the empirical analysis.

5.6 The Role of Scale

If higher industry prices alone explained the gain, non-member firms in the same product market should also share it. They do not: in a comparison restricted to industries with active cartels and with industry and industry-by-state fixed effects, outsider coefficients are substantially smaller than member coefficients and statistically indistinguishable from zero (Appendix A.1). The pattern is consistent with each of the three channels involving an excludable component. Under direct investment coordination, the contractual scope reaches only members. Under discipline-supplemented coordination, the disciplining institutions enter the firm through the boardroom, which is excludable. Under the returns-to-investment channel, the rent firms protect is itself contestable through the scale and excludability that the cartel organizes. The size of the member–non-member gap is itself informative: it indicates that cartel membership built scale within the firm rather than diffusing through product-market prices.

6 Spillovers, Aggregates, and the War Economy

Part B turns to the consequences of cartels for the rest of the economy and the state. The member-firm gains documented in Section 4 raise three questions of incidence: whether cartels imposed costs on downstream customers; how far those costs were contained by the contracts of the cartel

Table 5: Member-Firm Outcomes by Industry Characteristics

	Firm Value		Trade		Innovation	
	Survival	Stock Price	Exporter	FDI	Patents	Breakthrough
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Fixed cost reliance						
Cartel Member	0.03***	0.03	0.08***	0.01	0.02**	0.003
	(0.005)	(0.03)	(0.01)	(0.01)	(0.008)	(0.002)
Cartel Member × Upstreamness	0.010*	0.09*	0.020*	0.03*	0.015*	0.010*
	(0.006)	(0.05)	(0.01)	(0.02)	(0.009)	(0.006)
R^2	0.32	0.71	0.43	0.82	0.56	0.32
Panel B: State interest						
Cartel Member	0.04***	0.01	0.09***	0.02*	0.02***	0.004*
	(0.005)	(0.03)	(0.01)	(0.01)	(0.007)	(0.002)
Cartel Member × Dual-Use Sector	0.008*	0.11**	0.018*	0.04*	0.014*	0.011*
	(0.005)	(0.05)	(0.01)	(0.02)	(0.008)	(0.006)
R^2	0.33	0.72	0.44	0.82	0.56	0.33
Panel C: Technology reliance						
Cartel Member	0.02**	-0.01	0.07***	0.01	0.01*	0.002
	(0.006)	(0.03)	(0.01)	(0.01)	(0.008)	(0.002)
Cartel Member × Foreign Patent Intensity	0.009*	0.10*	0.022**	0.03*	0.017*	0.012**
	(0.005)	(0.06)	(0.01)	(0.02)	(0.009)	(0.005)
R^2	0.32	0.71	0.44	0.82	0.57	0.33
Observations	43,344	34,057	43,344	43,344	43,344	43,344
Firms	2,890	2,046	2,890	2,890	2,890	2,890
Years	52	51	52	52	52	52
Outcome Mean	0.95	5.67	0.34	0.24	0.11	0.01
Cluster	Firm	Firm	Firm	Firm	Firm	Firm
Firm fixed effects	✓	✓	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓	✓	✓

Note Table presents results of estimating equation (1), with an indicator of whether firm i is a member of any cartel in year t interacted with ex ante proxies for returns to investment: upstreamness (fixed-cost intensity), dual-use industry status (state procurement and military demand), and 1880s foreign-patenting intensity (export-market access). Observations are at the level of a firm-year. The number of firm-years and firms in each sample is indicated in the table. Firm-level outcomes are an indicator of firm i being active in year t, the inverse hyperbolic sine of the stock price of firm i in year t, an indicator of firm i exporter status in year t, an indicator of firm i FDI status in year t, the inverse hyperbolic sine of the number of patents filed by firm i in year t, and the CPC breadth of patents filed by firm i in year t. Firm and year fixed effects are included in all columns. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

system itself; and how the resulting organizational infrastructure shaped aggregate labor demand and wartime mobilization. We address these in three subsections.

6.1 Spillovers and Mitigation

A within-industry cartel that raises prices or restricts supply imposes an externality on downstream industries. Coasian reasoning (Coase, 1960) implies that such an externality can be internalized when the affected parties themselves contract—that is, when an inter-cartel agreement cov-

ers the industry pair. The empirical question is whether inter-cartel agreements served this role. Appendix Figure A.3 visualizes the German economy in input–output space, locates industries with active cartels on the network, and marks industry pairs covered by inter-cartel agreements; it motivates the decomposition below.

We estimate

$$FirmOutcome_{it} = \beta\, CartelExposure_{it} + \gamma\, CartelMember_{it} + \alpha_i + \alpha_t + \varepsilon_{it}, \tag{3}$$

where $CartelExposure_{it}$ is cartel exposure ($\sum_{s'} InputShare_{ss'} \cdot CartelShare_{s't}$, summing the upstream cartel share over the input-output weights of the industry s of firm i) and $CartelMember_{it}$ is an indicator of whether firm i is a member of any cartel in year t. To separate negotiated from non-negotiated spillovers, we decompose $CartelExposure_{it}$ into $ExposureNegotiated_{it}$ (negotiated cartel exposure (cartel exposure restricted to upstream industries s' that have an inter-cartel agreement with the industry of firm i)) and $ExposureNotNegotiated_{it}$ (non-negotiated cartel exposure (the complementary component of cartel exposure over industry pairs without an inter-cartel agreement)), and replace $\beta\, CartelExposure_{it}$ by $\beta_N\, ExposureNegotiated_{it} + \beta_U\, ExposureNotNegotiated_{it}$, where the subscripts denote negotiated (N) and non-negotiated (U) exposure.

Table 6 reports the estimates. Non-negotiated upstream cartel exposure is associated with worse downstream performance across firm value, trade, and innovation. Negotiated upstream cartel exposure is statistically indistinguishable from zero.

The contrast between the two coefficients is consistent with the Coasian interpretation: when an upstream and a downstream cartel contract over the spillover, the downstream cost of upstream cartelization is substantially attenuated. We therefore interpret the results as evidence that the cartel system contained part of its own distortions through cross-sector negotiation, not as evidence that cartels imposed no spillovers in the first place.

Table 6: Cartel Exposure and Downstream Firm Outcomes

	Firm Value		Trade		Innovation	
	Survival	Stock Price	Exporter	FDI	Patents	Breakthrough
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Pooled Exposure						
Cartel Exposure	-0.007	0.06	0.05**	0.10***	0.06***	0.01**
	(0.007)	(0.05)	(0.02)	(0.02)	(0.01)	(0.006)
R^2	0.32	0.69	0.43	0.82	0.56	0.32
Panel B: Pre- vs. Post-1904						
Pre-1904 Exposure	-0.004	-0.22***	-0.02	0.05	-0.005	-0.01**
	(0.010)	(0.07)	(0.04)	(0.03)	(0.03)	(0.006)
Post-1904 Exposure	0.008*	0.09*	0.05**	0.11***	0.06***	0.02**
	(0.005)	(0.05)	(0.02)	(0.02)	(0.01)	(0.006)
R^2	0.32	0.69	0.43	0.82	0.56	0.32
Panel C: Negotiated vs. Not						
Non-Negotiated Exposure	-0.006	-0.08	0.01	-0.04*	-0.02*	-0.004
	(0.008)	(0.06)	(0.03)	(0.02)	(0.01)	(0.005)
Negotiated Exposure	0.010*	0.12**	0.06**	0.12***	0.07***	0.02**
	(0.006)	(0.05)	(0.02)	(0.02)	(0.01)	(0.006)
R^2	0.32	0.69	0.43	0.82	0.56	0.32
Observations	36,963	29,607	36,963	36,963	36,963	36,963
Firms	2,890	2,046	2,890	2,890	2,890	2,890
Years	52	51	52	52	52	52
Outcome Mean	0.95	5.67	0.34	0.24	0.11	0.01
Cluster	Firm	Firm	Firm	Firm	Firm	Firm
Firm fixed effects	✓	✓	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓	✓	✓

Note Table presents results of estimating equation (3). Observations are at the level of a firm-year. The number of firm-years and firms in each sample is indicated in the table. The dependent variables are firm outcomes from Section 4 (an indicator of firm i being active in year t, the inverse hyperbolic sine of the stock price of firm i in year t, an indicator of firm i exporter status in year t, an indicator of firm i FDI status in year t, the inverse hyperbolic sine of the number of patents filed by firm i in year t, and the CPC breadth of patents filed by firm i in year t), as introduced in Section 3. Regressors include an indicator of whether firm i is a member of any cartel in year t, the component of the input-share-weighted upstream cartel share of the industry of firm i in year t restricted to upstream industries with an inter-cartel agreement in place, and the component of the input-share-weighted upstream cartel share of the industry of firm i in year t restricted to upstream industries without an inter-cartel agreement. Firm and year fixed effects are included. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

6.2 Aggregate

We complement the firm-level analysis with a county–industry–census-year panel from Section 3.5. Let c index counties, s industries, and t census years. We estimate

$$Y_{cst} = \beta\, Cartel_{cst} + \gamma X_{cst} + \mathcal{F}_{cst} + \varepsilon_{cst}, \tag{4}$$

where Y_{cst} is the inverse hyperbolic sine of employment in observation (c, s, t), $Cartel_{cst}$ indicates whether the observation contains at least one cartel member, and X_{cst} is a vector of observation-level controls. $\mathcal{F}_{cst}$ denotes alternative fixed-effect structures.

Table 7 reports estimates across six specifications. Column (1) includes county, industry, and year fixed effects. Column (2) adds county-by-industry fixed effects, identifying β from within-aggregate changes over time. Column (3) adds county-specific linear trends. Column (4) uses county-by-year fixed effects, identifying β from within-county, cross-industry comparisons. Column (5) uses industry-by-year fixed effects to absorb national industry-specific shocks. Column (6) combines county-by-year and industry-by-year fixed effects.

The estimates indicate that county–industry aggregates with cartel presence are not systematically smaller than those without in terms of aggregate employment. Read together with the spillover analysis above, this pattern is consistent with cartels supporting investment and production at the member-firm margin while limiting, within the system itself, distortions that would otherwise offset those gains in the aggregate.

Table 7: Cartels and Census Employment

	Employment (ihs)				
	(1)	(2)	(3)	(4)	(5)
Cartel firms (ihs)	0.55***	0.91***	0.20**	0.19**	0.32***
	(0.14)	(0.18)	(0.09)	(0.09)	(0.08)
Observations	492,100	492,100	492,100	492,100	492,100
R^2	0.08	0.67	0.74	0.78	0.91
Counties	925	925	925	925	925
Industries	76	76	76	76	76
Years	7	7	7	7	7
Cluster	County	County	County	County	County
Number of Firms	✓	✓	✓	✓	✓
County fixed effects	✓	✓			
Year fixed effects	✓	✓	✓		
Industry fixed effects		✓			
Industry-County fixed effects			✓	✓	✓
County-Year fixed effects				✓	✓
Industry-Year fixed effects					✓

Note Table presents results of estimating equation (4). Observations are at the level of a county–industry–census-year observation. The dependent variables are the inverse hyperbolic sine of total employment in the observation. The treatment is an indicator that the observation contains at least one cartel member. Columns differ in the fixed-effects structure as described in the text: county+industry+year (1), county-by-industry (2), county-by-industry plus county-specific linear trends (3), county-by-year (4), industry-by-year (5), and county-by-year plus industry-by-year (6). Standard errors are clustered at the county level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

6.3 War Economy Embedding

Finally, we ask whether the coordination organizations documented above formed part of the organizational infrastructure of wartime mobilization. We estimate a cross-sectional regression that links firm-level involvement in the wartime economies of World War I and World War II to 1913 cartel membership:

$$WarInvolvement_{is} = \beta\, Cartel_{is,1913} + \alpha_s + \alpha_c + \gamma' X_{is} + \varepsilon_{is}, \tag{5}$$

where $WarInvolvement_{is}$ is in turn an indicator of firm i receiving military contracts, the count of war-related patents of firm i in World War I, and an indicator of firm i involvement in the forced labor system during World War II; $Cartel_{is,1913}$ is an indicator of whether firm i is a member of any cartel in year t measured in 1913; α_s and α_c are industry and county fixed effects; and X_{is} is the vector of pre-period controls from Section 3.7.

Table 8 reports the estimates. Firms with pre-war cartel membership were more likely to receive military contracts (0.06; clustered standard error 0.02), to file war-related patents in World War I (0.02; 0.01), and to be involved in the forced-labor system during World War II (0.05; 0.02).

These estimates indicate that cartels formed part of the organizational infrastructure through which mobilization was carried out. The post-1945 decartelization campaign of the Allied Decartelization Branch (Crane, 2023) and the prosecution of senior cartel executives at the IG Farben trial thus aimed to dismantle this infrastructure. Appendix B.5 reproduces primary sources on the post-war consensus. The historical record is therefore consistent with the view that cartels formed part of a coordination infrastructure, including for regime purposes.

7 Conclusion

We study cartels in Germany between 1882 and 1945. We assemble the universe of 2,374 cartels, link them to 30,793 joint-stock firms, and combine the resulting panel with inter-cartel agreements, input–output linkages, court decisions, and declassified wartime records. We use these data to trace the consequences of an organizational form through which independent firms coordinated investment, production, and prices.

Table 8: Cartels and the War Economy

	War Procurement (1)	War Innovation (2)	Forced Labor (WWII) (3)
Cartel Member	0.19***	0.27**	0.28***
	(0.06)	(0.13)	(0.09)
Observations	3,417	3,417	3,417
R^2	0.20	0.09	0.19
Firms	3,417	3,417	3,417
Cluster	County	County	County
Controls	✓	✓	✓
Industry fixed effects	✓	✓	✓
County fixed effects	✓	✓	✓

Note Table presents results of estimating equation (5). All outcomes are standardized to mean zero and unit variance. Observations are at the level of a firm. The number of firms in each sample is indicated in the table. The dependent variables are (1) an indicator of firm i receiving military contracts, (2) the count of war-related patents of firm i in World War I, and (3) an indicator of firm i involvement in the forced labor system during World War II, as introduced in Section 3. The treatment is an indicator of whether firm i is a member of any cartel in year t measured in 1913. Industry and county fixed effects and the full set of pre-period controls from Section 3.7 are included. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

Our findings do not imply a mechanical link between firm coordination and industrial development, still less welfare. In the German case, the cartel system generated substantial investment gains for member firms and partly mitigated downstream distortions, but it also created a coordination infrastructure that was later available for war mobilization. Within this system, the state appears less as a top-down manager of industrialization than as a facilitator: enforcing cartel contracts, limiting rent extraction, and mediating disputes across cartels.

Although our findings are specific to the historical setting we study, two broader lessons emerge. First, they are most relevant to frictional environments in which externalities are large. This applies not only to early industrialization, but more generally to settings with high fixed costs, including periods of rapid technological change. Second, they point to the role of accountable disciplining institutions—banks, the state, and research institutions—in ensuring that the financial leeway generated by price coordination is invested rather than appropriated.

This, however, points to a tension. If frictional environments are also associated with weaker institutional accountability, the dynamic commitment problem at the core of this development model may be difficult to resolve (Itskhoki and Moll, 2019).

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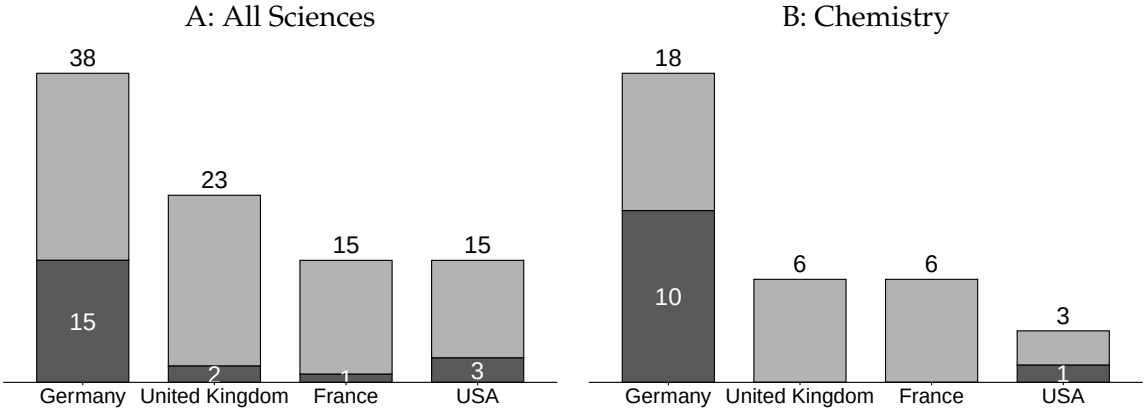
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A Additional Tables and Figures

This appendix collects additional figures and tables referenced in the main text.

Figure A.1: Nobel Prizes in the Sciences before 1939, by Country



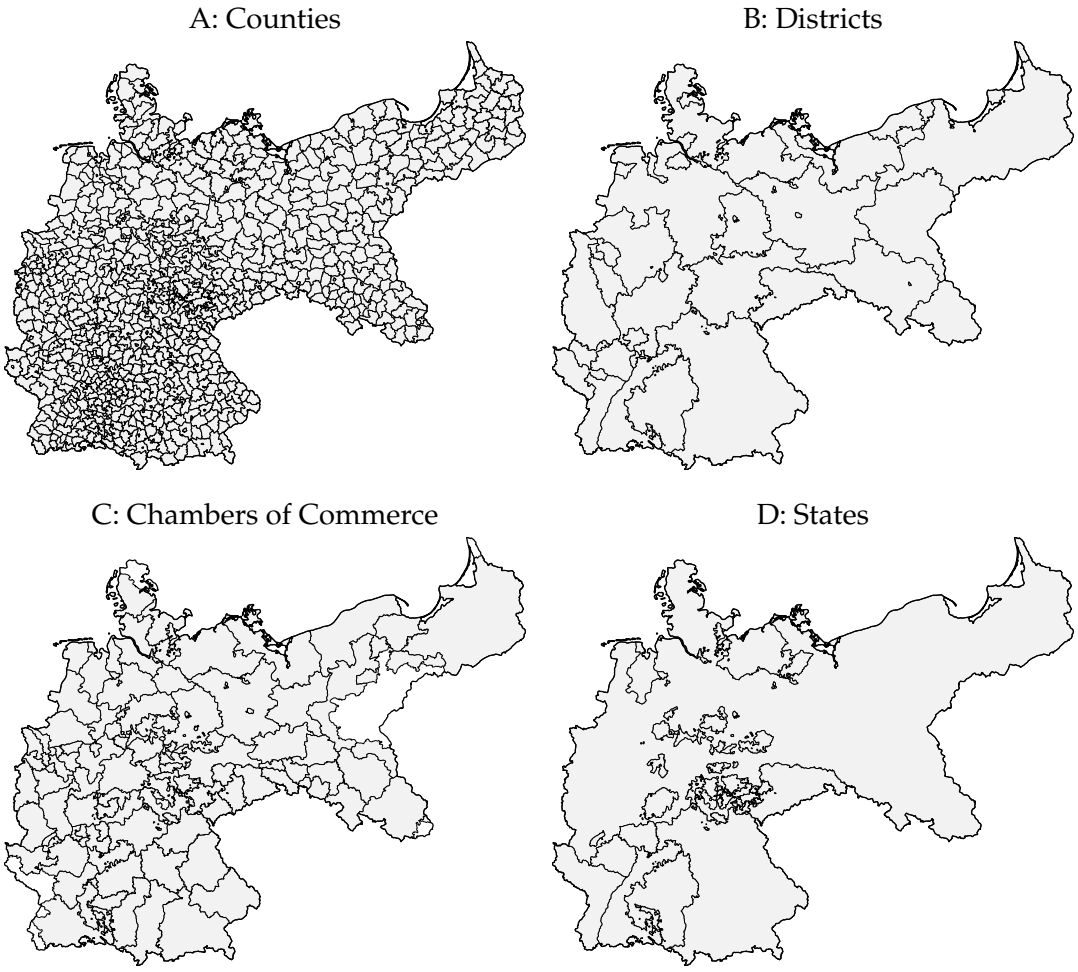
Note Figure reports the cumulative number of Nobel Prize laureates by country, 1901–1939. Panel A aggregates laureates in Chemistry, Physics, and Physiology or Medicine; Panel B restricts to Chemistry. Within each country, the figure separates laureates with a firm affiliation at the time of the prize-winning work from laureates without such an affiliation. Source: coding by the authors of Nobel Foundation records matched to contemporary firm rosters.

A.1 Outsider Comparison

Table A.1 reports the outsider comparison referenced in Section 5.6. We restrict the sample to industries with at least one cartel member and compare members to non-members within the same industry, using industry and industry-by-state fixed effects. Outsider coefficients are substantially smaller than member coefficients and statistically indistinguishable from zero.

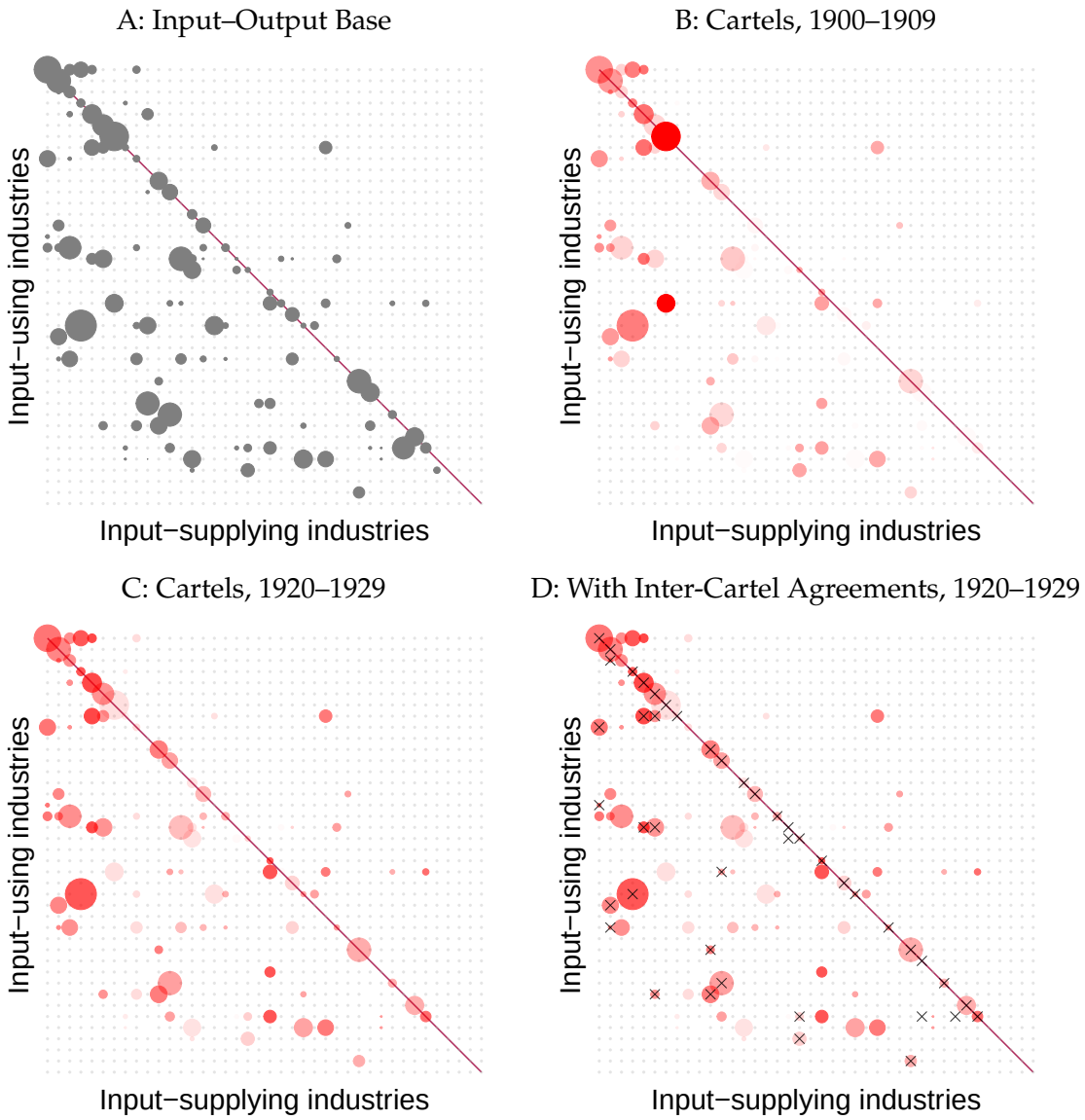
A.2 Geographic Units

Figure A.2: Geographic Units



Note Panel A: counties (900). Panel B: trade districts. Panel C: Chambers of Commerce (184). Panel D: states.

Figure A.3: The German Economy in Input–Output Space



Note Figure projects the German industrial economy onto a two-dimensional representation of input–output space. Panel A displays the base network, with each node an industry and each edge an input–output linkage weighted by $InputShare_{ss'}$. Panel B shades industries by the share of firms in a cartel during 1900–1909; Panel C repeats for 1920–1929. Panel D overlays inter-cartel agreements between industry pairs over 1920–1929. Data introduced in Section 3.

Table A.1: Member Firms vs. Outsiders

	Firm Value		Trade		Innovation	
	Survival	Stock Price	Exporter	FDI	Patents	Breakthrough
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Outsider comparison (industry-year)						
Cartel Member	0.05***	-0.02	0.09***	0.02*	0.02***	0.006**
	(0.005)	(0.02)	(0.01)	(0.010)	(0.007)	(0.003)
Observations	43,265	34,057	43,265	43,265	43,265	43,265
R^2	0.38	0.77	0.46	0.84	0.59	0.37
Industry-Year fixed effects	✓	✓	✓	✓	✓	✓
Panel B: Outsider comparison (state-industry-year)						
Cartel Member	0.05***	-0.02	0.10***	0.02*	0.03***	0.008**
	(0.006)	(0.03)	(0.01)	(0.01)	(0.008)	(0.003)
Observations	40,974	32,828	40,974	40,974	40,974	40,974
R^2	0.45	0.81	0.55	0.86	0.66	0.48
State-Industry-Year fixed effects	✓	✓	✓	✓	✓	✓
Firms	2,890	2,046	2,890	2,890	2,890	2,890
Years	52	51	52	52	52	52
Outcome Mean	0.95	5.67	0.34	0.24	0.11	0.01
Cluster	Firm	Firm	Firm	Firm	Firm	Firm
Firm fixed effects	✓	✓	✓	✓	✓	✓
Year fixed effects	✓	✓	✓	✓	✓	✓

Note Table presents results of estimating equation (1), restricted to industries with at least one cartel member, and augmented with an "outsider" indicator that equals one for non-member firms in industries with active cartels. Observations are at the level of a firm-year. The number of firm-years and firms in each sample is indicated in the table. Firm-level outcomes are an indicator of firm i being active in year t, the inverse hyperbolic sine of the stock price of firm i in year t, an indicator of firm i exporter status in year t, an indicator of firm i FDI status in year t, the inverse hyperbolic sine of the number of patents filed by firm i in year t, and the CPC breadth of patents filed by firm i in year t. Industry and industry-by-state fixed effects are included in addition to firm and year fixed effects. Standard errors are clustered at the firm level. *, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent level, respectively.

B A Case Study: The Chemical Industry

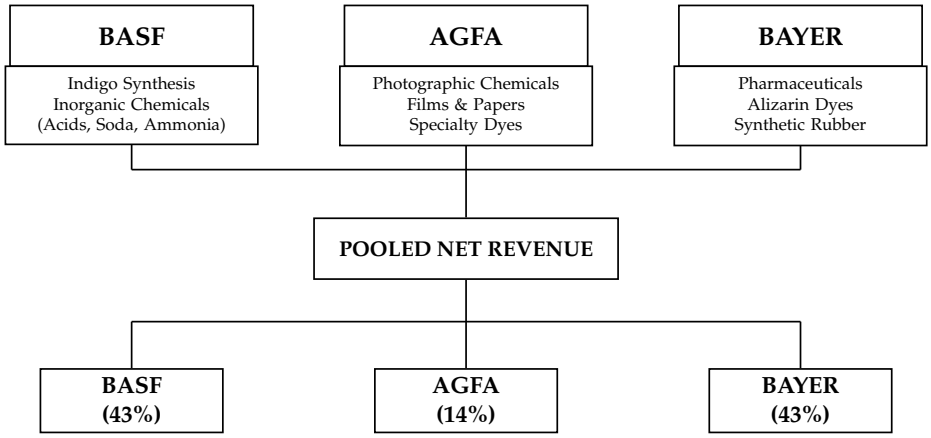
This appendix traces a single episode of catch-up industrialization — the German chemical industry from the 1890s to the 1925 merger of IG Farben — as an illustration of the coordination-organizations framework developed in the main text. The episode is useful for two reasons. First, the chemical industry was responsible for a disproportionate share of German innovation during the period (Figure A.1): Fritz Haber and Carl Bosch received Nobel Prizes in 1918 and 1931 for work sustained inside the cartel. Second, the institutional arrangements documented in Section 2 — cartel contracts, cross-sector negotiations, and state facilitation — are each visible in the chemical case at a resolution that our firm-level panel cannot capture.

B.1 The *Dreibund* of 1904

By 1900, the dye industry had reached the technological frontier in synthetic organic chemistry but faced three constraints that no single firm could resolve: financing of multi-year R&D, scientific risk-sharing, and coordinated supply of industrial inputs. 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). Member firms retained separate balance sheets and management but pooled a share of operating profits, agreed on territorial and product-line specialization, and jointly financed long-horizon research projects.

Figure B.1 reproduces the organizational diagram of the *Dreibund* as documented in the contemporary cartel statutes.

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



Note Organizational structure of the *Dreibund* (BASF, Bayer, Agfa, 1904). Nodes represent member firms and contracting counterparties; edges represent profit-pooling, R&D-sharing, or product-specialization clauses recorded in the cartel statutes. Source: reconstruction by the authors from cartel statutes in the *Kartell-Rundschau* and secondary sources.

B.2 Synthetic Nitrogen: Haber–Bosch and the Supply Chain

Mounting concerns about the adequacy of natural nitrate supply around the turn of the century lifted the payoff to an industrial process that could fix atmospheric nitrogen. No single firm had the scientific, engineering, or financial capacity to develop such a process unilaterally: the reaction required pressures and temperatures that no existing industrial equipment could sustain, and the scale-up involved decade-long investment horizons. The *Dreibund* channeled retained earn-

ings into roughly 20,000 catalyst trials, secured long-term coal supply contracts with the Rhenish-Westphalian Coal Syndicate, and coordinated with an extended set of supplier firms:

- **Mannesmann** supplied the seamless steel tubes required for the first high-pressure reactor prototypes.
- **Krupp** developed specialized chromium steels capable of withstanding the ∼200-bar operating conditions of the industrial Haber–Bosch reactor at Oppau.
- **Auergesellschaft** supplied the osmium catalyst used in the first effective laboratory-scale synthesis; BASF bought out Auer's osmium stock on Haber's advice in 1909.
- **Linde** provided the cryogenic gas separation technology used in the early hydrogen-production program.
- **Griesheim-Elektron** supplied hydrogen through its electrochemical chlor-alkali process.
- **The state** co-financed the first-plant scale-up at Oppau.

The process was brought to industrial scale in 1913. By 1926, roughly 65% of the operating profits of the successor firm, IG Farben, were attributable to synthetic nitrogen products. Haber (1918) and Bosch (1931) received Nobel Prizes for work sustained inside this cartel-organized supply chain.

Figure B.2 shows the wartime repurposing of the Haber–Bosch infrastructure during World War I. When the British naval blockade cut off imports of Chilean nitrate, the *Dreibund* modified its fertilizer process to produce the nitrogen-based explosives on which German munitions production depended.

Figure B.2: The *Dreibund* and World War I Mobilization



Note Photograph of a *Dreibund* nitrogen plant during World War I. Source: archival photograph reproduced with historical attribution.

B.3 The Indigo Cartel and Market Displacement

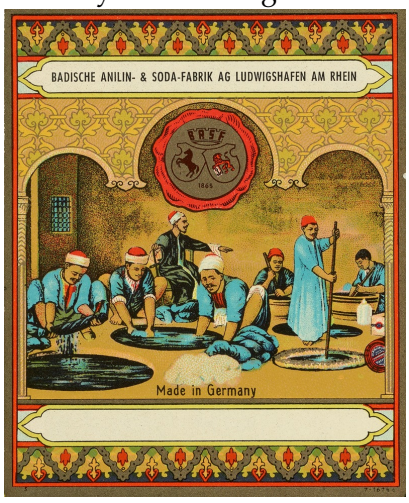
A parallel episode in the same firms illustrates how coordinated R&D plus coordinated exports displaced an entire global industry. Natural indigo, a dye cultivated in India for textile use, had an

export volume of roughly 10,000 tons in 1895. German chemical firms, under a 1904 indigo-specific cartel agreement that followed the *Dreibund* template, pooled patents on four alternative synthetic routes, agreed on product specialization (BASF focusing on indigo; Bayer relinquishing it), jointly negotiated coal purchases, and operated a shared U.S. sales office. By 1910, Indian indigo exports had fallen by approximately 90%, and synthetic German indigo dominated world markets.

Figure B.3 reproduces period advertisements that document the export posture of the cartel.

Figure B.3: Synthetic Indigo and Cartel Export Advertising

A: BASF Synthetic Indigo Trade Card



B: Bayer Export Directory Ad, 1907



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

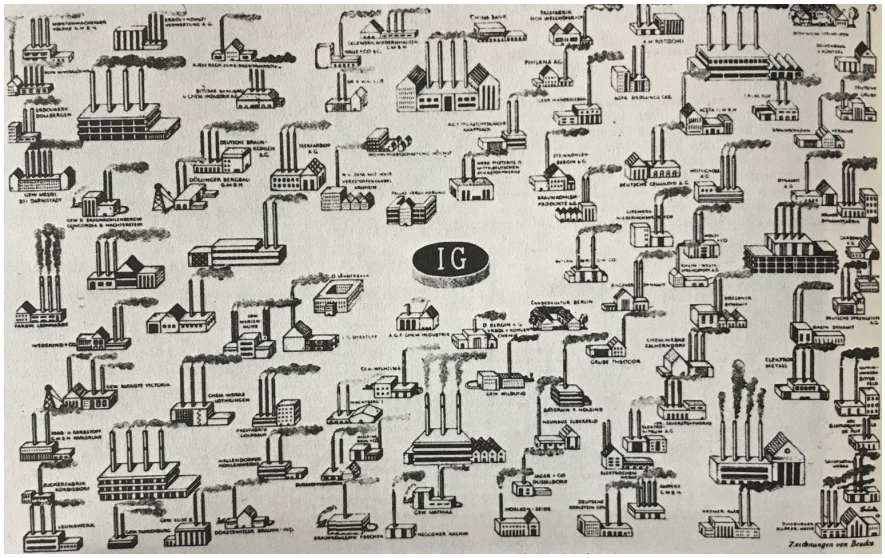
B.4 From Cartel to Merger: IG Farben (1925)

By the mid-1920s, the *Dreibund* had expanded into a broader Interessengemeinschaft ("community of interests") comprising nearly all of the leading German chemical firms. In 1925, the members merged into a single joint-stock corporation, IG Farben (Figure B.4). The merger completed a sequence that began with an enforceable cartel contract (1904), extended through cross-firm R&D coordination and supply-chain integration (1904–1913), was repurposed for wartime mobilization (1914–1918), and was consolidated into a single legal entity (1925).

B.5 Post-War Decartelization

The centrality of the chemical cartel to two wartime mobilizations shaped the post-war Allied response. Figure B.5 reproduces two primary sources: a *New York Times* front page documenting the emerging Allied consensus on post-war decartelization in September 1944, 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 (Crane, 2023), created under military government, targeted the chemical cartel system — the same organizational infrastructure documented in this appendix — as its primary object of dismantlement.

Figure B.4: IG Farben Merger, 1925



Note Organizational diagram of the 1925 IG Farben merger. Source: Feldenkirchen (1987).

Figure B.5: Post-War Sources on Cartels

A: *New York Times*, 8 September 1944

ROOSEVELT CALLS FOR CARTELS CURB

In Letter to Hull He Says Types of 'Trusts' Used by Reich Must Be Ended

By JOHN H. CRIDER
Special to THE NEW YORK TIMES.

WASHINGTON, Sept. 8—President Roosevelt singled out the cartel problem at his news conference today as one of the most important which must be met in the next few months.

He made public a letter to Secretary Hull in which he called for the "eradication" in Germany of "these weapons of economic warfare" and, urging action beyond

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.6 Reading the Case Study

The chemical case study is consistent with the quantitative evidence in the main text along four margins. First, the member-firm gain in Section 4 corresponds to the observable performance of BASF, Bayer, Agfa, and their counterparts: survival, patenting, and exports all rose. Second, the investment-based mechanism in Section 5 is visible in the allocation of retained earnings to catalyst trials, the accumulation of bank and engineer directors in the boardrooms of cartel members, and the vertical ties to steel, coal, and hydrogen suppliers (Appendix B.2). Third, the Coasian mitigation in Section 6.1 corresponds to the explicit cross-sector contracts — export-rebate arrangements with coal, long-term supply contracts with steel — that internalized upstream and downstream externalities. Fourth, the war-economy embedding in Section 6.3 is the explosives-production redirection documented in Figure B.2, and the post-war consolidation of that infrastructure under Allied decartelization (Appendix B.5, Figure B.5). The case study is a single draw, but it matches the full sequence of empirical claims in the paper.

C Framework

This appendix formalizes the contrast between unrestricted price competition and price coordination in supporting cost-reducing investment. The framework is deliberately stylized — two firms, a homogeneous good, and a discrete upgrade decision — and its purpose is to make precise the equilibrium logic underlying the mechanism discussion in Section 5: why operating profits are required to sustain the upgrade, why coordination on the high-investment outcome is not automatic, and how the static cost of price coordination trades off against its productive-efficiency gain.

C.1 Setup

Consider a duopoly with firms $i \in \{1, 2\}$ producing a homogeneous good. Inverse demand is

$$P(Q) = a - bQ, \qquad a > c_H > c_L > 0, \quad b > 0,$$

with direct demand $Q(p) = (a - p)/b$ at price $p \leq a$. The game has two stages.

Stage 1 (investment). Firms simultaneously choose whether to upgrade their technology, $x_i \in \{0, 1\}$. Choosing $x_i = 1$ requires a fixed investment cost $K > 0$.

Technology. The investment exhibits strict complementarity: both firms obtain the low marginal cost only if both upgrade. Realized marginal costs are

$$c_i(x_1, x_2) = \begin{cases} c_L & \text{if } x_1 = x_2 = 1, \\ c_H & \text{otherwise.} \end{cases}$$

Costs are therefore symmetric across firms in every subgame.

Stage 2 (product market). Firms sell to consumers. We compare two regimes: unrestricted (Bertrand) price competition and price coordination at an exogenous level $\bar{p}$.

C.2 Flexible Prices

Under flexible prices, Stage 2 is standard Bertrand competition with a homogeneous good and symmetric marginal cost $c \in \{c_H, c_L\}$. In every continuation game $p = c$, and each firm's operating profit is zero. Conditional on realized cost c, total quantity is

$$Q(c) = \frac{a - c}{b},$$

and total surplus equals consumer surplus,

$$TS(c) = \int_0^{Q(c)} (a - bq - c)\, dq = \frac{(a - c)^2}{2b}.$$

Because operating profits are zero whether costs are c_H or c_L, a firm that chooses $x_i = 1$ pays the sunk investment cost K but receives no operating benefit. Upgrading is therefore strictly dominated, and the unique Stage-1 Nash equilibrium is $(x_1, x_2) = (0, 0)$. Realized cost is c_H, and equilibrium total surplus under flexible prices is

$$TS^F = \frac{(a - c_H)^2}{2b}.$$

C.3 Price Coordination

Suppose now that the output price is set exogenously at $\bar{p}$, with $a > \bar{p} > c_H > c_L$. Total quantity demanded is $Q(\bar{p}) = (a - \bar{p})/b > 0$. Since $\bar{p} > c_H$, both firms are willing to supply at that price in every subgame. We assume demand is rationed equally across firms, so each firm serves

$$q_i(\bar{p}) = \frac{Q(\bar{p})}{2} = \frac{a - \bar{p}}{2b}.$$

Let $q \equiv (a - \bar{p})/(2b)$. Stage-1 payoffs (operating profit minus investment cost) are

$$\Pi_i(0,0) = (\bar{p} - c_H)q, \qquad \Pi_i(1,0) = (\bar{p} - c_H)q - K,$$

$$\Pi_i(0,1) = (\bar{p} - c_H)q, \qquad \Pi_i(1,1) = (\bar{p} - c_L)q - K.$$

No upgrade is always an equilibrium. If the rival chooses $x_j = 0$, complementarity fails regardless of firm i's action; firm i obtains the same operating profit either way but pays K if it upgrades. Hence $\Pi_i(0,0) > \Pi_i(1,0)$, and $x_i = 0$ is a strict best response to $x_j = 0$. The profile $(0,0)$ is therefore a Nash equilibrium of Stage 1 under price coordination as well.

Joint upgrade is an equilibrium iff the investment gain exceeds the cost. If the rival chooses $x_j = 1$, firm i compares $\Pi_i(1,1) = (\bar{p} - c_L)q - K$ with $\Pi_i(0,1) = (\bar{p} - c_H)q$. Hence $(1,1)$ is a Nash equilibrium iff

$$K \leq (c_H - c_L)\, q = \frac{(c_H - c_L)(a - \bar{p})}{2b}. \tag{6}$$

Price coordination thus does not make joint upgrade the unique equilibrium: $(0,0)$ is always an equilibrium, and $(1,1)$ is an additional equilibrium whenever the per-firm operating gain at the supported price covers the investment cost. Selection of the high-investment equilibrium is itself a coordination problem.

C.4 Welfare

Suppose the high-investment equilibrium $(1,1)$ is selected, so that realized marginal cost is c_L. Total surplus equals gains from trade up to quantity $Q(\bar{p})$ minus the two investment costs:

$$TS^P = \int_0^{Q(\bar{p})} (a - bq - c_L)\, dq - 2K = \frac{(a - c_L)^2 - (\bar{p} - c_L)^2}{2b} - 2K.$$

Equivalently, TS^P decomposes into consumer and producer surplus net of investment,

$$TS^P = \underbrace{\frac{(a - \bar{p})^2}{2b}}_{\text{consumer surplus}} + \underbrace{(\bar{p} - c_L)\frac{a - \bar{p}}{b}}_{\text{producer surplus}} - 2K.$$

The supported price exceeds marginal cost c_L and therefore generates a static deadweight loss. With efficient quantity $Q^*(c_L) = (a - c_L)/b$ and efficient surplus $TS^*(c_L) = (a - c_L)^2/(2b)$,

$$DWL = TS^*(c_L) - \int_0^{Q(\bar{p})} (a - bq - c_L)\, dq = \frac{(\bar{p} - c_L)^2}{2b}. \tag{7}$$

This is the static allocative loss conditional on successful adoption and realized cost c_L; it does not include the investment cost $2K$.

Comparing regimes, the equilibrium under price coordination delivers higher total surplus than the equilibrium under flexible prices iff

$$\frac{(a-c_L)^2-(\bar{p}-c_L)^2}{2b}-2K>\frac{(a-c_H)^2}{2b},$$

or, equivalently,

$$(c_H-c_L)\,\frac{2a-c_H-c_L}{2b}>\frac{(\bar{p}-c_L)^2}{2b}+2K. \tag{8}$$

The left-hand side is the gross productive-efficiency gain from lowering marginal cost from c_H to c_L; the right-hand side is the sum of the static deadweight loss from the price wedge and the total investment cost.

D Data Processing

E Robustness

References

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