Colluding against Workers

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Empirical models of labor market competition usually assume that employers set wages noncooperatively, despite frequent allegations of collusive employer behavior. We propose an identification approach for labor market collusion that relies on production and cost data, and we use it to study how employer collusion affected wage markdowns of 227 Belgian coal firms between 1845 and 1913. We are able to detect collusion through the 1897 coal cartel without ex ante knowledge of its timing and find that it explains the fast growth in markdowns after 1900. We find that the cartel decreased both wages and employment by 6% to 17%.

I. Introduction

There are growing concerns about increasing levels of labor market power held by firms (Krueger 2018; Manning 2021; Sokolova and Sorensen

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2021). Whereas current empirical labor market models focus on many sources of imperfect competition, such as labor market frictions (Caldwell and Harmon 2019), concentration (Schubert, Stansbury, and Taska 2022), or employer differentiation (Card et al. 2018), they usually assume noncooperative wage setting by employers. However, there are frequent allegations of wage fixing and no-poaching agreements in various industries, for instance between high tech firms, fast food chains, oil companies, and universities (Naidu, Posner, and Weyl 2018, 597–98; US Department of Justice 2019; Krueger and Ashenfelter 2022; Gibson 2024). The extent to which employer collusion drives the wedge between the marginal product of labor and wages, the wage markdown, remains an open question. The answer to this question is crucial when designing policies to constrain monopsony or oligopsony power.[1] For instance, antitrust policy has a key role in addressing wage markdowns that are derived from collusion between employers, but not if they arise from noncooperative sources, such as search frictions or employer differentiation.

In this paper, we close this gap in the literature by developing an empirical approach to detect and quantify employer collusion in labor markets using firm-level production, cost, and wage data. Our approach consists in estimating wage markdowns using a production-cost model that does not impose labor market conduct assumptions and comparing these to markdown bounds that employers would charge if they would not collude or if they would perfectly collude. Knowledge of these markdown bounds requires imposing a model of labor supply, in addition to the labor demand conditions derived from the production model. A similar comparison was done for goods price markups by De Loecker and Scott (2016) but without inferring conduct and assuming perfectly competitive factor markets.

Given that employer collusion in current-day settings is illegal and hence usually unobserved, this paper takes a historical turn. We apply our method to examine the extent to which wage markdowns of 227 Belgian coal firms between 1845 and 1913 were due to collusion or to other sources of imperfect competition. The Belgian coal setting, specifically, is relevant to our research question because of three reasons. First, cartels were legal throughout the nineteenth century, which allows us to observe collusion. In the Belgian coal setting, a cartel was formed in 1897, and there is also evidence of collusive wage setting through the membership of employers' associations, professional organizations where firm executives met on a regular basis to discuss current industry developments and

allowing access to their collection. This paper benefited greatly from the thoughtful feedback of three referees and the editor. This paper was edited by Rachel Griffith.

[1] For the remainder of the paper, we use the terms "monopsony" and "oligopsony" for labor market power interchangeably. We note that literal monopsonies are scarce.

wage setting. This allows us to compare our wage collusion estimates, which do not require observing collusion, to observed collusive behavior. Second, the coal industry offers a rare case in which rich microdata can be retrieved over a uniquely long period that covers most of the industrialization of Belgium, the first country on the European continent to participate in the Industrial Revolution. Third, the coal industry features limited product differentiation, which facilitates the empirical analysis. Despite these special characteristics of the historical Belgian coal setting, our method can be applied to any other industry for which production, cost, and wage data are available, and we illustrate that it can be extended to settings with differentiated goods and/or multiproduct firms.

Our findings can be summarized as follows. During a first period, up to the 1870s, wage markdowns were stable, with workers being paid around two-thirds of their marginal product at the median firm. During the 1880s and 1890s, markdowns increased, leaving workers with around 60% of their marginal product. Finally, after 1900, markdowns increased even further, leaving workers less than 50% of their marginal product. By comparing our markdown levels to noncollusive and fully collusive markdown bounds, we can unpack this markdown increase into collusive and other sources. We find that prior to 1900, the rise in wage markdowns was mostly due to noncollusive sources. The degree of collusion was roughly constant throughout this time period and hence does not explain markdown growth prior to 1900.

Contrary to this, the sharp increase in wage markdowns after 1900 was entirely due to collusion. Wage markdowns jumped to the fully collusive level right after the emergence of the Liège coal cartel in 1897. As 75% of the market was controlled by this cartel, markdowns arose not only at the cartel participants but also at the other firms in the same market. Our test for labor market collusion cannot reject the null hypothesis of zero collusion from 1901 onward. Crucially, our empirical approach would have been able to detect the increased collusion after the introduction of the cartel, without observing this cartel. This increase in employer collusion had important implications for workers. We find that the cartel decreased both equilibrium wages and employment by 6%–17% compared to the observed precartel labor market conduct, which was already partly collusive. Compared to a counterfactual world without any labor market collusion, the cartel decreased wages and employment by 10%–25%.

These results have external validity beyond the nineteenth-century coal setting. First, they help understanding the labor market effects of cartels today. Given that output is more easily observed than inputs, firms might be more inclined to collude on output quantities or prices, even if the possible goal is to exert market power upstream rather than downstream. We show that in settings with imperfect labor market competition, output-restricting cartels can lead to substantial wage markdown growth and the exertion of monopsony power, even if firms are faced with relatively competitive product markets downstream. Our model can also be used to detect the existence of employer collusion in current-day labor markets, as well as to examine its effects. Second, the results bear historical external relevance beyond the Belgian coal industry. In *The Condition of the Working Class in England*, Engels (1892, 241–60) lamented the "cheating" and "plundering" by the "coal kings," as British coal owners' associations actively fixed wages (Church 1986, 651–74). Moreover, Belgian coal mines were located within commuting distances of industrial cities and shared many labor market characteristics with these other industries. This differs from earlier historical studies on labor market power of US coal mining firms, which are usually geographically isolated (for appraisals, see Fishback 1992; Boal 1995). Hence, it is likely that our findings are not confined to the coal industry alone. The introduction of cartels was not specific to coal. It also took place in many industries both in Europe and the United States, and we know that collusion was not unique to coal firms but was also present in many other industries, such as the steel industry for instance.

This paper contributes to three strands of literature. First, we contribute to the literature on imperfectly competitive labor markets. Empirical models of imperfect labor market competition usually impose untested assumptions about firm conduct and competition, such as monopsonistic competition (Card et al. 2018; Lamadon, Mogstad, and Setzler 2022) or oligopsonistic competition (Azar, Berry, and Marinescu 2022; Berger, Herkenhoff, and Mongey 2022). We contribute to this literature by allowing for collusive wage setting and by examining how labor market conduct changes when cartels are formed downstream. In contrast to Roussille and Scuderi (2023), who also test between different models of labor market conduct, we rely on a production model to help identify conduct and allow for collusive behavior of employers on the labor market.

Second, we build on work on conduct identification in the industrial organization literature. Most empirical research on collusion follows a demand-side approach, in the tradition of Bresnahan (1987), with the key challenge being that both marginal costs and conduct are latent. Possible solutions are to identify shifts in collusion, rather than its level (Ciliberto and Williams 2014), to rely on in-sample variation in ownership (Miller and Weinberg 2017), or to find instruments that are orthogonal to affect only marginal costs but not conduct, or vice versa (Michel and Weiergraeber 2018; Backus, Conlon, and Sinkinson 2021). If one has production-cost data, however, a production model like in De Loecker and Warzynski (2012) can be used to identify markups without making explicit conduct assumptions, which has been extended to analyze factor markets by Dobbelaere and Mairesse (2013), Mertens (2020), Morlacco (2020), Brooks et al. (2021), Yeh, Macaluso, and Hershbein (2022), and

Rubens (2023b, 2024). We rely on a combination of both approaches, as in De Loecker and Scott (2016), to identify conduct. Our results show that cartels on product markets can have very large effects on anticompetitive behavior on input markets. This calls for taking into account downstream competition when studying imperfectly competitive factor markets.

Third, we contribute to the economic history of employer collusion. We touch on an “old” question in economics: were workers exploited during the Industrial Revolution, and to which extent was this due to collusion between employers? Indeed, Adam Smith (1976, 75) already highlighted the unequal position between employer and employee, remarking on the “combinations” that masters entered to sink the wages below the competitive rate, “conducted with the utmost silence and secrecy,” while any attempts of collusion by workers were met with “the loudest clamour.” The economic history literature consequently contains ample evidence for employer collusion on labor markets, for instance through guilds and other coercive institutions (Naidu and Yuchtman 2018; Humphries and Schneider 2019; Ogilvie 2019; Jedwab, Johnson, and Koyama 2022). Throughout the nineteenth century, employers increasingly unionized in employers’ associations, which sought to defend commercial interests and counter emerging trade unions (Yarmie 1980; Vanthemsche 1995). We contribute to these findings by using our model to empirically examine the effects of these employers’ associations. We find that employers’ associations were crucial vehicles of wage collusion for most of the nineteenth century but that they lost this function due to the emergence of cartels during the 1890s. Hence, the surge of cartels after the turn of the century in Europe and the United States, which was documented in Murray and Silvestre (2020) for the coal industry and Lamoreaux (2019) from a more general perspective, provided opportunities for collusion not only on the product market but also on the labor market.

The remainder of this paper is structured as follows. Section II describes the historical setting of Belgian coal mining and presents the data. In section III, we present the empirical model of labor supply, demand, and conduct. In section IV, we estimate our model and test for employer collusion. We use the estimated model to examine the consequences of the 1897 coal cartel for miners’ wage and employment levels. Section V provides a range of robustness checks. Finally, section VI concludes.

II. Industry Background and Facts

A. Data

Our main data source is a novel dataset that collects annual reports by the Administration des Mines, a state agency that employed engineers to annually inspect all Belgian coal mines. Its archives for Belgium’s provinces of Liège and Namur are exceptionally well preserved, as well as consistently formatted over time.[2]

For the 227 firms in our dataset, we observe annual coal extraction in tons by type of coal and coal prices at the mine gate. Employment is reported in numbers of workers and in days, with a distinction between underground and surface workers. The data report expenditure on, literally, "nonlabor ordinary expenses" and "extraordinary expenses." The latter category includes all expenses that involve "mine construction, mine transformation and other expansion costs" (Wibail 1934). Hence, we consider the former to be intermediate input expenditure and the latter to be fixed capital investment. Besides capital investment, we also observe the total horsepower of the various machine types used per firm, up to 1899. We use these different capital measures to construct the capital stock using a perpetual inventory method, as explained in detail in appendix section B.3.

The administration data come at the level of mining concessions, in which the state grants permission to a person or firm to mine its natural resources. Concessions can be composed of multiple mines (production units). In theory, the same individual or firm could operate multiple concessions simultaneously; however, in practice this almost never happened in the Liège and Namur provinces as firms who owned multiple concessions immediately merged these into a single concession. Hence, we can assume that the concession-level unit of observation in the data corresponds to mutually independent firms. We motivate this assumption in depth in appendix section B.1.3.

We complement the inspection reports with various other data sources. We obtain yearly information on each firm's membership of an employers' association by digitizing the monthly *Bulletin* of the Union des Charbonnages, Mines et Usines Métallurgiques de la Province de Liège, for the Liège basin, and of the Association Charbonnière et l'Industrie Houillière des Bassins de Charleroi et de la Basse-Sambre, for the Namur basin. We also observe membership in coal cartels using the cartel lists from De Leener (1904). Furthermore, we link the municipalities in which the firms are located to data on opening dates of railroad and tramway stations. Hence, we know for every firm in every year whether it was connected to the railroad and tramway networks. Finally, we deflate all nominal variables in the dataset using the consumer price index of Segers (2003), which we extend to 1845 using Scholliers (1995).

[2] We refer to app. sec. B.1 for all details concerning the data collection and processing, as well as more historical background on the Administration des Mines.

B. *Coal Demand and Production*

1. Coal and the Industrialization of Belgium

Belgium's Industrial Revolution, the first on the Continent, started when Walloon entrepreneurs imitated British technological innovations during the eighteenth century.[3] The macroeconomic effects of these innovations materialized during the following decades, with industrial production taking off from the middle of the nineteenth century: during the 1850s and 1860s, Belgium became an economic powerhouse (Gadisseur 1979; Pluymers 1992). This growth trend continued into the age of globalization, as technologically advanced firms fueled strong export performance in coal-based sectors such as metal and steel production (Huberman, Meissner, and Oosterlinck 2017).

The presence of rich and easily accessible coal deposits in the south of the country played an important role in Belgium's industrialization (Allen 2009, 104). As a result, the coal mining industry became a major industrial employer, with its share of industrial employment surpassing 10% at the turn of the nineteenth century (Buyst, forthcoming). At the local level, the labor market share of coal mining employment was much higher: in the city of Liège, one out of five workers was active in the coal sector in 1896, with some surrounding communities having more than half of their labor force active in the mines. We illustrate this local concentration of economic activity using 1896 community-level data in figure D.4 (figs. B.1–D.12 are available online).

The coal labor force was distributed among three provinces in Belgium's industrial belt, namely (from west to east) Hainaut, Namur, and Liège. A distinction is typically made among the coal basins of the Borinage, Centre, Charleroi (all three in the province of Hainaut), Basse-Sambre (in Namur), and Liège. In this paper, we focus on the coal mines in Liège and Namur because we have access only to the necessary data for these provinces, which together represented approximately three out of 10 coal workers and 20%–25% of coal production in Belgium.[4] There were on average 60 coal firms per year active in the Liège basin and 19 in the Namur basin. The main buyers of coal were households (22% of sales), steel mills (20%), railroads (13%), producers of cokes (10%), and nonferrous metal manufacturers (10%; De Leener 1908).

[3] This is clearly illustrated by the case of the first Newcomen machine on the Continent, which was constructed in Tilleur, near Liège, only 8 years from its inception in 1712 (Lebrun et al. 1981, 263, 313).

[4] These employment shares are based on the industrial censuses of 1846 and 1896 from Delabastita and Goos (2024). Production shares are based on Statistique de la Belgique (1858) and the *Annales de Mines de Belgique* (Administration des Mines 1896, 505). We refer to app. sec. D.1 for more background information the Belgian coal industry.

2. Production Process and Technological Change

Extracting coal required, roughly speaking, four steps. First, the underground coal vein had to be reached by digging a mine shaft. Second, the coal had to be extracted. This was done manually by the miners (known as *abatteurs* or *ouvriers à veine*) with pickaxes. Third, the lumps were hauled to the surface in containers or mine carts by mules and laborers, *hiercheurs*, often young children and women. Fourth, coal had to be sorted from debris, which was done at the surface.

Throughout the sample period, there was extensive capital accumulation and mechanization. Coal haulage was already mechanized at the start of our sample period, as steam-powered underground mining locomotives were introduced around 1812. The ratio of locomotive horsepower per employee-day used remained fairly constant over the sample period.[5] Two other forms of mechanization were, however, increasingly adopted during the nineteenth century. First, mechanical pumps were introduced to remove water from the mines. These were initially steam powered, but from 1893 electrically powered pumps were introduced (Gaier 1988, 72). The usage of water pumps mainly increased during the 1870s. Second, steam-powered ventilation fans were introduced from the 1870s onward to deal with sudden releases of firedamp. In contrast, coal cutting was mechanized very little in Liège and Namur throughout our sample period. Pneumatic coal cutting machines would be implemented in Liège coal mining only around 1908 and with little success: the coal veins were too narrow to use cutting machines.[6] This contrasts with, for instance, the case of the United States, where these cutting machines were readily adopted from 1882 (Rubens 2024). We discuss the implications of potential factor-biased technical change on our model and results in section V.II.

C. Labor Markets

1. Labor Relations and Wage Setting

Due to the high population density in Belgium, manufacturing and mining firms could easily tap into low-cost labor (Mokyr 1976). Belgium was indeed labeled as a low-wage country by contemporaries, despite its industrial successes. Government intervention on labor markets remained all but nonexistent throughout the nineteenth century, as politicians held true to the liberal laissez-faire principles on which Belgium was founded in 1830. Given that suffrage was conditional on wealth until 1893, a mere 1%

[5] We show this in fig. D.5*a*.

[6] At the 1905 World's Fair in Liège, organized to showcase the region's industrial leadership, local industrialists had to grudgingly admit that the introduction of mechanical cutting techniques was hampered by difficult geological conditions (Drèze 1905, 816).

of the population held voting rights. This pushed questions on topics such as worker rights and living conditions to the political periphery. Marx, in a letter to Engels, called Belgium “the snug, well-hedged, little paradise” of the capitalist (Marx and Engels 1985, 47).

Labor legislation had been drafted under French rule at the beginning of nineteenth century and generally placed laborers in an unfavorable position by prohibiting collective bargaining for wages or working conditions. Article 414 of the criminal code prohibited labor coalitions until 1866, when this article was replaced by the criminalization of strikes, which remained illegal until 1921. Large-scale labor movements consequently knew little to no development for the larger part of the nineteenth century. Belgian trade unions were only in the embryonic stages of their development in the nineteenth century, and employers did not recognize them as legitimate partners for collective bargaining until the First World War (Luyten 1995, 16).

Wage contracts were informal and primarily oral, and legal hiring and firing costs were virtually nonexistent (Van den Eeckhout 2005). Salaries were determined using either time or piece rates, with the latter typically reserved for miners and other more skilled workers. The only source of government intervention in labor markets was the worker *livret*, a sort of worker’s passport, which was abolished in 1883. These livrets could in theory be withheld from workers by employers to prevent workers from switching jobs. In practice, however, microevidence shows that this requirement did not stop coal workers from being highly mobile among employers. Coal workers were indeed highly mobile: on average, more than half of the Liège-based coal workers changed workplaces 10–24 times within their careers (Leboutte 1988, 49). With respect to sector mobility, coal employees were typically considered a specialized yet socially homogeneous worker class whose economic fate was unmistakably intertwined with the fortune of the coal industry. Nonetheless, seasonal or permanent moves to other industries were likely not uncommon but neither were reentrances into the profession of coal mining (Leboutte 1988, 47–55).[7]

2. Output per Worker and Wages

Figure 1*A* plots the evolution of output per worker and daily wages in the Liège and Namur coal basins during our sample period. From 1845 to 1875, both wages and output per worker grew proportionally. During the late 1870s and 1880s, wage growth stalled despite increasing output

[7] Our baseline model in sec. III.B does not incorporate cross-industry mobility. We extend our model to allow for this by including an outside option containing noncoal industries in app. sec. C.2.3.

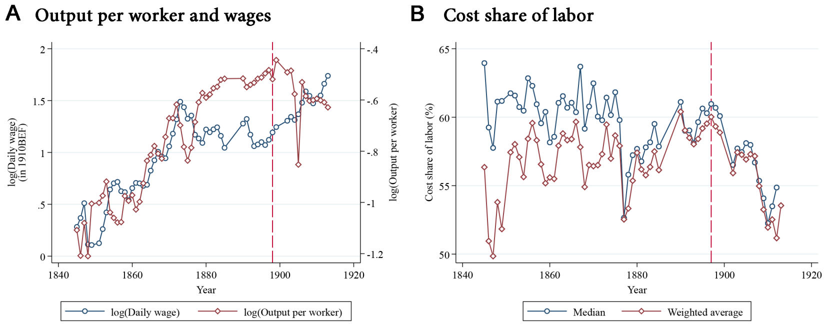

FIG. 1.—Output per worker, wages, and cost shares in Liège- and Namur-based coal mining, 1845–1913. *A*, The logarithm of total output divided by total days worked in Liège and Namur coal mines and the evolution of the logarithm of the average daily miner wage, weighted across mines by employment shares. *B*, The median and the average labor cost share of total expenditure, weighted by employment shares.

per worker. In the late 1890s, wages grew again while output per worker started to fall. These changes can be interpreted in many ways other than as evidence of monopsony power. Output per worker is not equal to the marginal revenue product of workers because there are more inputs than labor and because product markets might be imperfectly competitive. For instance, capital investment seems important here. The increasing wedge between output per worker and wages during the 1870s coincides with increased capital investment and mechanization during those years, as shown in figure D.5*b*. Due to these issues, a production model is necessary to correctly identify the wedge between the marginal revenue product of labor and wages. We will expand this model in section III.[8]

Figure 1*B* plots the median and weighted average cost share of labor over time, defined as total labor expenditure over total input expenditure.[9] Until the 1890s, the median cost share of labor was relatively stable, whereas the weighted average cost share grew, indicating reallocation of inputs toward high labor cost share firms. After 1900, both the median and average labor cost share fell. This trend could either indicate technological change or a drop in the relative price of labor compared to the other inputs. We will take this up in the empirical model of section III and examine this in further detail in section V.II.

[8] Another reason for this changing wedge could be compensating differentials due to risk premiums: we measure the actual wage, not the risk-adjusted wage. We argue that risk premiums are not a crucial driver of wage markdowns in our setting in app. sec. C.3.1.

[9] We also refer to table B.5, which presents summary statistics on the cost shares and on other concession characteristics.

D. Collusion

Two types of firm collusion are observed throughout the sample period. First, firms coordinated wages through employers' associations. Second, coal cartels were introduced during the late 1890s, which imposed output quota on cartel participants.

1. Employers' Associations

Similar to worker collusion, employer collusion on the labor market was illegal. However, the law stipulated much harsher punishment for worker collusion and included a vague and difficult-to-prove condition that employer collusion had to be "unjust" and "abusive" to be punishable (Stevens 1998, 402). Labor market collusion between employers was facilitated by employer unions or so-called employers' associations, a type of syndicate that was formed in many industries throughout the nineteenth century.[10] In the Liège coal mining industry, several mines united in the form of the Union des Charbonnages Liégeois in 1840, which was publicly registered in 1868 under the name of the Union des Charbonnages, Mines et Usines Métallurgiques de la Province de Liège. Thirty-three percent of firms in our dataset were members of an employers' association, but they produced 80% of output. Many small firms did not join these associations, likely because voting rights were granted based on the number of employees, causing employers' associations to be dominated by the large employers. The official objective of the Union des Charbonnages was to defend the interests of the local coal and metal industries, and its annual reports reveal its role as a lobby group to fight government intervention in issues such as child labor, female labor, working conditions, or labor unionization (Union des Charbonnages 1869–1913).

The union's committee convened on a monthly basis to discuss current industry developments and to coordinate all kinds of employment decisions (De Leener 1909, 138). Importantly, the employers' association served to "coordinate salary fluctuations" (De Leener 1904, 234). This aligns with the general perception of these early employers' associations in the nineteenth century as collusive devices (Dubois 1960, 6–10). Two characteristics stand out. First, its all-encompassing nature is striking. We know that employers did not necessarily collude with respect to wages only but also on employment, collective insurances against inactivity due to strikes, and so forth. Collusion on employment frequently took place,

[10] An analysis of current-day employer unions is done by Martins (2020), who studies how firm performance measures differ between members of such unions and other firms.

primarily in the form of agreements on working hours, which are encapsulated in our employment variable (for examples, see De Leener 1904, 122–26). Second, collusion was typically of an informal nature, as the Union des Charbonnages did not impose formal quotas or punish deviant behavior. In Mons, coal firm unions suspected that authorities would never bother to enforce the aforementioned regulation against labor coalitions, but they stuck to oral agreements as to not warn authorities of their labor coalition violations (Lefèvre 2004). Some clear-cut cases of collusive wage setting in Belgian coal mining are known, however, as managers of Hainaut-based coal firms controlled by the universal bank Société Générale de Belgique openly compared the wages paid at their respective firms and deviations from collusive wage levels were heavily frowned on (Mottequin 1973, 367). This anecdotal evidence indicates that multilateral agreements among nineteenth-century employers were rife and suggests that this collusive wage- or employment-setting behavior happened through employers' associations.

2. Coal Cartels

As in many other industrializing countries, Belgian industries saw a strong increase in the number of (product market) cartels from the 1870s onward. The number of official cartels in Belgium, which were legal and incorporated as firms, increased from five to 80 between 1880 and 1910. The coal industry was no exception: on July 1, 1897, 27 coal firms in Liège entered a cartel, the Syndicat de Charbonnages Liégeois. The Syndicat was set up as a société anononyme, in which the partaking firms committed to waiving the vending rights of their production to the cartel. The directors of the coal firms assembled at least 12 times a year and convened at the demand of a democratic majority. Voting rights were proportional to each firm's output, in addition to a fixed number of votes per firm. The amount of coal sold was determined and constrained by a collectively decided quota in terms of tonnage. Individual coal firms remained responsible for their own customer relationships. Cartel firms who sold more than the agreed upon quantity were fined BEF 50 per excess ton (compared to an average price of BEF 9.7 per ton in 1898), while other violations of the cartel statutes were fined BEF 1,000. In this framework, the cartel sold between 75% and 80% of total sales in the Liège *bassin*, with the remainder being taken up by the dissenters. Although the Syndicat did not impose any quota on employment or other input expenditures, reduced output also led to reduced employment, as we will show later on. The cartel agreement was binding for a period of 5 years, and it was renewed until 1935, when it was replaced by a national coal cartel, the Office National des Charbons (Vanthemsche 1983).

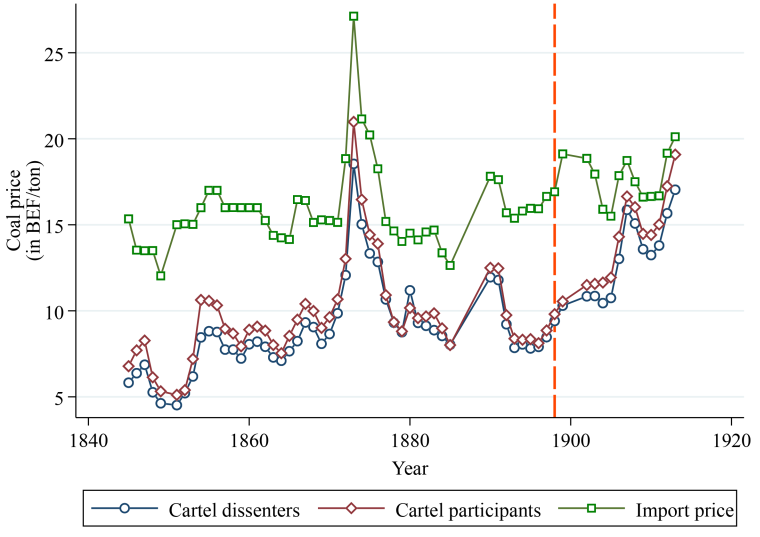

FIG. 2.—Prices and the Liège coal cartel, 1845–1913. The dashed vertical line represents the start of the coal cartel, the Syndicat de Charbonnages Liégeois.

The effect of this cartel can be clearly seen by comparing the Liège coal price to the import price of coal in Belgium.[11] We plot this import price in figure 2. Up to 1897, the Liège coal price was well below the import price of coal at the Belgian border. Following the cartel introduction in 1897, the Liège coal price increased up to the level of imported coal. A cartel would not price above this import price, as this would induce coal buyers to substitute toward imported coal. The cartel also seems to have had implications for the cost share of labor: as was shown in figure 1*B*, the cost share of labor dropped after 1897, indicating that the cartel could have had labor market implications as well. We will examine this hypothesis in the empirical model.

III. Empirical Model

In this section, we set up an empirical model of labor supply and demand to identify collusive conduct by Belgian coal firms. Our approach consists in comparing wage markdown estimates from a production model, which does not impose conduct assumptions on the labor market, with wage markdown bounds that are derived from a labor supply model, both in the absence of collusion and under fully collusive employer behavior.

[11] This import price is computed as total value of imported coal at the border divided by imported quantity of coal; hence, it includes transport costs from foreign mines to the border.

A. Production Function

We start with a model of coal production. Output Q_{ft} indicates the tonnage of coal extracted during a given year t by firm f. In this analysis, we assume coal to be a homogeneous product, as there is generally limited variation in coal quality. To do so, we sum the output of coal across the different coal categories of caloric content that the historical sources differentiate.[12] Mines often extracted a combination of these coal types, which are a function of the geological characteristics of the mine's location. We argue that this is innocuous because the caloric content of coal does not affect mining productivity.[13]

Firms use two variable inputs: L_{ft}, which captures the amount of effective labor throughout the year, and the amount of intermediate inputs purchased, M_{ft}. The capital stock consists of steam engines used for water pumping, coal hauling, and ventilation. The value of total capital used at each mine is denoted K_{ft}. Logarithms of variables are denoted in lowercase. As our baseline specification, we assume a Cobb-Douglas production function (1) with output elasticities β^{l}, β^{m}, and β^{k}, and log total factor productivity ω_{ft}:

$$q_{ft} = \beta^{\mathrm{l}} l_{ft} + \beta^{\mathrm{m}} m_{ft} + \beta^{\mathrm{k}} k_{ft} + \omega_{ft}. \tag{1}$$

We specify a Cobb-Douglas production function in labor, capital, and materials, rather than specifying a production function with nonsubstitutable material inputs, because material inputs were to some extent substitutable.[14] For materials and labor, this can be illustrated with the example of mine tunnel excavation, an important activity in nineteenth-century coal production. Firms can vary their materials-to-labor usage ratio by digging tunnels using explosives to open up new areas for coal extraction, or by relying more heavily on labor.[15] We assume that the output elasticities $\boldsymbol{\beta}$ are constant over time, which we relax in appendix section C.1.4. In appendix section C.1.3, we extend the production model to a more flexible

[12] Four coal types are distinguished in the dataset based on volatile content percentiles: 13%–18% (houille maigre sans flamme; i.e., anthracite coal), 18%–26% (houille sèche courte flamme), 26%–32% (houille maigre longue flamme), and >32% (houille grasse longue flamme). The first type was mainly used by households for heating purposes, the second for powering steam engines, and the latter two types for railroad locomotives.

[13] To assert this assumption, we regress the estimated total factor productivity (TFP) residual on the share of high-quality coal and obtain an R^2 below 10^{-5}. We extend the model to allow for differentiated output in app. sec. C.1.5. Appendix sec. C.1.10 provides an extension to multiproduct firms.

[14] Nonsubstitutable intermediate inputs would imply a production function such as $Q_{ft} = \min\{L_{ft}^{\beta^{\mathrm{l}}} K_{ft}^{\beta^{\mathrm{k}}} \Omega_{ft}; M_{ft}\beta^{\mathrm{m}}\}$, as in Ackerberg, Caves, and Frazer (2015). We refer to Rubens (2023b) for factor price markdown identification in settings with nonsubstitutable inputs.

[15] Although firms can substitute between labor, capital, and materials under Cobb-Douglas, we note that the Cobb-Douglas functional form implies that these inputs are Q-complements (Stern 2011).

functional form by estimating a translog production function. In our baseline model, we do not impose any assumptions on the returns to scale (RTS) in the production process, but we also present an extension in which we impose an RTS parameter in the main text. In appendix section C.1.2, we present further details on the latter approach.

The Cobb-Douglas specification rules out factor-biased technological change. We see this as an innocuous assumption because, as was explained in section II.B, capital investment in Liège mines was mainly limited to mining locomotives and lifts, ventilation fans, and water pumps. Ventilation fans and water pumps are safety investments, which can be seen as a sunk cost to operate the mine, but which do not affect labor productivity specifically. Rubens (2023a) did not find evidence for labor augmenting effects of mining locomotives. The main factor-biased technology in mining was the mechanized cutting machine, which was not skill-biased (Rubens 2024). However, such machines were barely adopted in the mines in our dataset due to too narrow coal veins, as mentioned earlier. We defend this assumption further in our setting using detailed technology data in section V.B.

We assume that the TFP transition is given by the first-order Markov process in equation (2), with an unexpected productivity shock v_{ft} and serial correlation ρ. The main benefits of this Markov process relate to the identification of the production function, as will be explained later. Of course, there are also costs to this approach: we rule out richer productivity processes that arise due to cost dynamics (we test this assumption in app. sec. C.1.11):

$$\omega_{ft} = \rho\omega_{ft-1} + v_{ft}. \tag{2}$$

We assume that both labor and intermediate inputs are variable and static inputs, meaning that they are not subject to adjustment frictions and affect only current profits. Capital is, in contrast, assumed to be a dynamic and fixed input: we assume capital investment is chosen 1 period in advance and affects both current and future profits, as capital does not depreciate immediately. We test these timing assumptions in section V.A by looking at the impulse-response functions of the different inputs after the coal demand shock of 1871.

B. *Labor Supply*

1. Labor and Intermediate Input Supply

Firms face a labor supply function with an inverse firm-level elasticity

$$\psi^{1}_{ft} \equiv \frac{\partial W^{1}_{ft}}{\partial L_{ft}} \frac{L_{ft}}{W^{1}_{ft}}.$$

If firms are wage takers on the labor market, this implies that $\psi^{\mathrm{l}}_{ft} = 0$, whereas labor market power implies that $\psi^{\mathrm{l}}_{ft} > 0$. We assume that firms are price takers on their intermediate input markets, meaning that

$$\psi^{\mathrm{m}}_{ft} \equiv \frac{\partial W^{\mathrm{m}}_{ft}}{\partial M_{ft}} \frac{M_{ft}}{W^{\mathrm{m}}_{ft}} = 0.$$

The Belgian coal industry was well integrated in the manufacturing sector and had to compete with other industrial sectors for material inputs such as tools, explosives, and black powder, so it seems reasonable to assume that these input markets were indeed competitive. We defend this assumption further and estimate an alternative model that allows for endogenous intermediate input prices in appendix section C.1.6.

2. Labor Supply Function

For our labor supply model, we rely on a static homogeneous firms model. The main reason to model firms as not being differentiated is that there is very limited wage variation across firms within towns: municipality-year fixed effects explain 93% of miner wage variation. Adding firm fixed effects increases the R^2 only to 94%. If firms would be differentiated in terms of nonwage amenities, this should translate into within-market wage differences. We present more evidence on the standard deviation and explanatory power of firm fixed effects for wages in appendix section C.2.1.[16] We provide a more formal test of employer differentiation in appendix section C.2.2. However, we emphasize that the assumption of homogeneous employers does not reduce the broader applicability of our approach to identify collusion. In appendix section C.2.3, we illustrate this by estimating a model with differentiated employers instead. Similarly, other sources of imperfect labor market competition, such as search costs, could be incorporated into the labor supply model, possibly introducing dynamics.

We assume a log-linear labor supply curve, equation (3), with inverse market-level elasticity Ψ^{l}. In the main specification, we assume that this elasticity is homogeneous across markets and time.[17] Wages W^{l}_{it} are the same for all firms within a labor market i in each year t. Market-level employment is denoted L_{it}, and a market-specific residual ν_{it} reflects variation in the relative attractiveness of different labor markets, for instance due to variation in outside options available to workers. The upward slope of the market-level labor supply curve can have different sources. For instance, even if local labor markets were nonfrictional, heterogeneity in

[16] Although a model of monopsonistic competition with amenities, such as a constant elasticity of substitution model, could result in homogeneous markdowns even with differentiation, this would still lead to wage heterogeneity due to differences in marginal labor products across firms.

[17] We relax this assumption in app. sec. C.2.4.

reservation wages across workers due to outside option differences would lead to an upward-sloping market-level labor supply curve:

$$W_{it}^{\mathrm{l}} = L_{it}^{\Psi^{\mathrm{l}}} \nu_{it}. \tag{3}$$

3. Markdowns and Markups

We define the ratio of the marginal revenue product of labor over the wage as μ_{ft}^{l}, and refer to this ratio as a markdown,

$$\mu_{ft}^{\mathrm{l}} \equiv \frac{\mathrm{MRPL}_{ft}}{W_{ft}^{\mathrm{l}}},$$

where the marginal revenue product of labor MRPL_{ft} is defined in the usual way, $\mathrm{MRPL}_{ft} \equiv \partial(P_{ft}Q_{ft})/\partial L_{ft}$.

Alternatively, the wage markdown is often expressed as a percentage markdown of wages below the marginal revenue product δ_{ft}^{l}, which is a simple function of μ_{ft}^{l}:

$$\delta_{ft}^{\mathrm{l}} \equiv \frac{\mathrm{MRPL}_{ft} - W_{ft}^{\mathrm{l}}}{\mathrm{MRPL}_{ft}} = \frac{\mu_{ft}^{\mathrm{l}} - 1}{\mu_{ft}^{\mathrm{l}}}.$$

Similarly, the coal price markup is defined as the ratio of the coal price over marginal costs, $\mu_{ft} \equiv \partial L_{ft}/\mathrm{MC}_{ft}$.

C. *Employer Behavior*

We assume that firms choose variable input quantities to minimize a combination of their own and their competitors' costs, as specified in equation (4). The collusion weights λ_{fgt} parametrize the weight that each firm f puts on the costs of every other firm g within the same input market $i(f)$, with the set of firms in market i being denoted $\mathcal{F}_{i(f)t}$. This is the cost minimization equivalent of the objective functions in empirical collusion models such as Bresnahan (1987). The shadow value parameter MC_{ft} captures the marginal cost of increasing output by 1 unit at firm f:

$$\min_{L_{ft}, M_{ft}} \left(\sum_{g \in \mathcal{F}_{i(f)t}} (\lambda_{fgt}(L_{gt}W_{gt}^{\mathrm{l}} + M_{gt}W_{gt}^{\mathrm{m}})) - \mathrm{MC}_{ft}(Q(L_{ft}, M_{ft}, K_{ft}, \Omega_{ft}; \boldsymbol{\beta}) - Q_{ft}) \right), \tag{4}$$

with $\lambda_{fgt} = 1$ if $f = g$ and $0 \leq \lambda_{fgt} \leq 1$ if $f \neq g$.

The collusion weights λ_{fgt} indicate the extent to which firms internalize only their own costs when choosing inputs or the costs of their competitors as well. If firms choose variable inputs to minimize only their own costs, this implies that the matrix of λ_{fgt} weights, Λ_t, is the identity matrix, in which case our model collapses to the one in De Loecker and Warzynski (2012).

If firms are colluding perfectly, they are choosing inputs to minimize joint costs, as if they would be a single firm, and Λ_t becomes a matrix of ones. This general formulation nests different kinds of collusive practices: for instance, firms can agree to a nonpoaching agreement or they can outright collude on their employment quantities (or wages). All these forms of collusive behavior are captured by the collusion parameter λ_{fgt}. We note that collusion on output quantities or prices is also picked up in terms of the collusion parameter λ_{fgt}: firms do not internalize each other's revenues and costs differently.[18]

We quantify the bounds of the wage markdown μ^{l}_{ft} under two different employer conduct assumptions: noncooperative employment choices and perfect collusion.[19] In appendix section A.1, we generalize the aforementioned model and identification approach to a broader class of models that does not rely on the homogeneous employers assumption, and that allows for different noncooperative baseline conduct than Cournot competition.

1. No Collusion

In the absence of collusion, firms choose inputs to minimize their own costs without internalizing their rivals' costs. Hence, the objective function in equation (5) assumes that firms choose their variable inputs L and M in every time period to minimize their current variable costs:

$$\min_{L_{ft},M_{ft}}\Big((L_{ft}W^{l}_{ft} + M_{ft}W^{m}_{ft}) - \mathrm{MC}_{ft}(Q_{ft} - Q(L_{ft}, M_{ft}, K_{ft}, \Omega_{ft}; \boldsymbol{\beta}))\Big). \quad (5)$$

Given that employers are assumed to be homogeneous to their workers, this implies a model of Cournot competition. Taking the first-order condition with respect to labor, adjusting wage subscripts to the fact that wages are market-specific, and rewriting marginal costs MC_{ft} as the coal price over the markup $\mu_{ft} \equiv P_{ft}/\mathrm{MC}_{ft}$ results in

$$L_{ft}\frac{\partial W^{l}_{it}}{\partial L_{it}} + W^{l}_{it} = \frac{\partial Q_{ft}}{\partial L_{ft}}\frac{P_{ft}}{\mu_{ft}}. \quad (6)$$

The right-hand side of equation (6) is equal to the marginal revenue product of labor, its left-hand side is the marginal cost of labor. Denoting the labor market share of firm f in market i as $s^{l}_{ft} \equiv L_{ft}/L_{it}$, it follows that the ratio of the marginal revenue product of labor over the wage is equal to the market-level inverse labor supply elasticity weighted by the labor

[18] In theory, one could distinguish different collusion weights on competitor sales and costs, but to separately identify these, one would need to impose a model of competition both downstream and upstream, whereas we only do the latter.

[19] Under perfect labor market competition, wages are equal to the marginal revenue product of labor, so $\mu^{l}_{ft} = 1$ and $\delta^{l}_{ft} = 0$.

market share, as shown in equation (7). We denote this markdown in the absence of collusion as $\underline{\mu}^{l}_{ft}$:

$$\underline{\mu}^{l}_{ft} = 1 + s^{l}_{ft}\Psi^{l}. \tag{7}$$

2. Collusion

Under perfect collusion, all firms in market i form a cartel that collectively chooses the input bundle that minimizes joint costs of all the firms, as defined by the set $\mathcal{F}_{i(f)t}$. This implies the objective function (8):

$$\min_{L_{ft}, M_{ft}} \left(\sum_{g \in \mathcal{F}_{i(f)t}} (L_{gt} W^{l}_{gt} + M_{gt} W^{m}_{gt}) - \mathrm{MC}_{ft}(Q_{ft} - Q(L_{ft}, M_{ft}, K_{ft}, \Omega_{ft}; \boldsymbol{\beta})) \right). \tag{8}$$

The first-order condition becomes equation (9). In contrast to the first-order condition in the Cournot case, equation (6), the firms do not optimize individually over their residual labor supply curve but jointly, treating the entire market-level labor supply curve as endogenous:

$$L_{it} \frac{\partial W^{l}_{it}}{\partial L_{it}} + W^{l}_{it} = \frac{\partial Q_{ft}}{\partial L_{ft}} \frac{P_{ft}}{\mu_{ft}}. \tag{9}$$

The resulting collusive markdown, which we denote $\bar{\mu}^{l}_{ft}$, is equal to the market-level inverse labor supply elasticity, as is expressed in equation (10). As firms choose inputs jointly, their collective labor market share is equal to 1, which rationalizes the collusive markdown (10) in comparison with the Cournot markdown (7):

$$\bar{\mu}^{l}_{ft} = 1 + \Psi^{l}. \tag{10}$$

3. General Formulation

To nest these two extreme cases of conduct into one specification, we rewrite the first-order conditions from equations (6) and (9) more generally as equation (11). We introduce a conduct parameter $\tilde{\lambda}_{ft}$ that parameterizes the extent of collusion in the market. If firms do not collude, the conduct parameter is equal to the labor market share, $\tilde{\lambda}_{ft} = s^{l}_{ft}$, and the first-order condition collapses to the Cournot model. In contrast, if firms collude perfectly, the conduct parameter is one, $\tilde{\lambda}_{ft} = 1$. The conduct parameter $\tilde{\lambda}_{ft}$ is a firm-level aggregate of the bilateral conduct parameters λ_{fgt} from equation (4):

$$W^{l}_{it} + \tilde{\lambda}_{ft} \frac{\partial W^{l}_{it}}{\partial L_{it}} L_{it} = \frac{\partial Q_{ft}}{\partial L_{ft}} \frac{P_{ft}}{\mu_{ft}}. \tag{11}$$

Working out this first-order condition results in the markdown expression in equation (12):

$$\mu_{ft}^{l} = 1 + \tilde{\lambda}_{ft}\Psi^{l}. \tag{12}$$

This expression nests the markdown bounds under no collusion, equation (7), and under perfect collusion, equation (10). In the next section, we will compare these markdown bounds to cost-side markdown estimates to identify collusion.

4. Timing of Choices

In accordance with the assumptions made above, the timing of choices is as follows. At time $t - 1$, prior to observing productivity shocks v_{ft}, firms choose their capital investment and decide whether to collude.[20] At time t, after the productivity shock materializes, they choose labor and intermediate inputs.

One caveat related to the model is that, as was mentioned earlier, there is anecdotal evidence for both wage fixing and employment coordination. The cartel restricted output and hence employment, which is more in line with the Cournot model. For the employers' associations, we find anecdotal evidence for both wage coordination, as was mentioned earlier, but also for various types of employment coordination. Given that we are mainly interested in the labor market effects of the cartel, we will rely on a model in which firms collude in their employment choices in the next section. We refer to appendix section C.2.3 for an alternative model with collusive wage setting, rather than employment setting.

D. Quantifying Employer Collusion

The model above shows that the labor supply elasticity allows us to identify the wage markdown μ_{ft}^{l} only under a specific assumption about employer conduct, as parameterized by the conduct parameter $\tilde{\lambda}_{ft}$. In this section, we show that the wage markdown can also be written independently of the conduct parameter but relying on the production function parameters instead.[21] Substituting the output elasticity of labor β^{l} and the revenue share of labor $\alpha_{ft}^{l} \equiv (W_{ft}^{l}L_{ft})/(P_{ft}Q_{ft})$ into the first-order condition for labor in the cost minimization problem, (11), results in the following markup expression, which is an extension of the markup expression in De Loecker and Warzynski (2012):

$$\mu_{ft} = \frac{\beta^{l}}{\alpha_{ft}^{l}(1 + \tilde{\lambda}_{ft}\Psi^{l})}.$$

[20] We do not formally model the underlying collusion decisions, which are likely dynamic.

[21] Again, we refer to app. sec. A.1 for the more general version of this argument beyond the homogeneous firms model.

The first-order condition for materials is identical to the markup derivation in De Loecker and Warzynski (2012). Given that intermediate input prices are exogenous to firms, we can write the following equation for markups:

$$\mu_{ft} = \frac{\beta^{\mathrm{m}}}{\alpha_{ft}^{\mathrm{m}}}. \tag{13}$$

Following previous work (Morlacco 2020; Brooks et al. 2021; Yeh, Macaluso, and Hershbein 2022) but now allowing for collusion, we divide the markup derived from labor by the markup derived from intermediate inputs to obtain the markdown equation (14). The right-hand side of this equation, $(\beta^{\mathrm{l}}\alpha_{ft}^{\mathrm{m}})/(\beta^{\mathrm{m}}\alpha_{ft}^{\mathrm{l}})$, is the cost-side markdown estimate, which does not depend on the conduct parameter $\tilde{\lambda}_{ft}$. The left-hand-side term, $1 + \tilde{\lambda}_{ft}\Psi^{\mathrm{l}}$, is the labor supply side markdown from the generalized Cournot model, which does depend on the conduct parameter:

$$\mu_{ft}^{\mathrm{l}} = 1 + \tilde{\lambda}_{ft}\Psi^{\mathrm{l}} = \frac{\beta^{\mathrm{l}}\alpha_{ft}^{\mathrm{m}}}{\beta^{\mathrm{m}}\alpha_{ft}^{\mathrm{l}}}. \tag{14}$$

Equation (14) captures the core of our empirical strategy. If we have an estimate of the market-level inverse labor supply elasticity Ψ^{l}, the wage markdown is known up to the conduct parameter $\tilde{\lambda}_{ft}$. The wage markdown is also known if the production function parameters are identified. Hence, identification of both the labor supply function and the production function permits identification of the conduct parameter $\tilde{\lambda}_{ft}$ by equating the two terms in equation (14).

Rather than estimating the conduct parameter $\tilde{\lambda}_{ft} \in [s_{ft}^{\mathrm{l}}, 1]$, we estimate a slightly altered conduct parameter $\hat{\lambda}_{ft} \in [0, 1]$ as defined in equation (15), which is more easily interpretable as it ranges from 0 to 1.[22] In the absence of collusion, $\hat{\lambda}_{ft} = 0$, whereas in a fully collusive market, $\hat{\lambda}_{ft} = 1$.

$$\hat{\lambda}_{ft} \equiv \frac{\mu_{ft}^{\mathrm{l}} - \underline{\mu}_{ft}^{\mathrm{l}}}{\bar{\mu}_{ft}^{\mathrm{l}} - \underline{\mu}_{ft}^{\mathrm{l}}}. \tag{15}$$

We operationalize this approach by following a stepwise approach. First, section IV.A presents the estimation of the production and labor supply functions. Second, in section IV.B, we estimate and discuss the evolution of wage markdowns. Third, in section IV.C, we quantify collusion and examine how it changed in response to the cartel. Finally, in section IV.D, we carry out counterfactual exercises to examine the employment and wage effects of collusion.

[22] It is easy to show that $\hat{\lambda}_{ft} = (\tilde{\lambda}_{ft} - s_{ft}^{\mathrm{l}})/(1 - s_{ft}^{\mathrm{l}})$.

IV. Identification, Estimation, and Results

A. *Labor Demand and Supply*

1. Production Function

We start by estimating the production function, equation (1). As is usual in the literature, we rely on timing assumptions on firms' input choices for identification, in the spirit of Olley and Pakes (1996). However, we combine these timing assumptions with a labor supply shifter to achieve overidentification, and we also test the timing assumptions, as will be explained further below. As labor and materials were assumed to be static and variable inputs, they are chosen after the productivity shock v_{ft} is observed by the firm at time t, while capital is fixed and dynamic, so investment is chosen before the productivity shock is observed at time $t-1$. Second, we rely on agricultural wage shocks as an additional instrument. It is a well-established fact in Belgian economic history that the Walloon coal belt attracted a large surplus of agricultural labor, predominantly from Flanders, the northern area of Belgium (Segers 2003, 334; Buyst, forthcoming). Hence, negative shocks to agricultural wages should have acted as positive labor supply shocks to coal mines. We include lagged agricultural wages in Belgium, as measured by Segers (2003, 622–23), in the instruments vector. The assumption here is that changes in agricultural wages in the previous year, w_{t-1}^{agri}, affected labor supply to the mines but did not affect coal mining productivity directly.[23] In table D.4 (tables C.1–D.4 are available online), we provide evidence on the first stage by regressing the annual change in log total mining employment in the Liège and Namur coal basin on the annual change in log agricultural wages in Belgium. Negative agricultural wage shocks were indeed followed by increased coal mining employment. Following these assumptions, we can now write the moment conditions to estimate the mining production function as

$$\mathbb{E}[v_{ft} | (l_{fr-1}, m_{fr-1}, k_{fr}, w_{r-1}^{\text{agri}})]_{r\in[2,.,t]} = 0. \tag{16}$$

The usual approach in the literature is to invert the intermediate input demand function to recover the latent productivity level ω_{ft}, which can be used to construct the productivity shock v_{ft} using the productivity law of motion (Olley and Pakes 1996; Levinsohn and Petrin 2003; Ackerberg, Caves, and Frazer 2015). This approach hinges on productivity being the only latent, serially correlated input demand shifter. However, input

[23] We include lagged agricultural wages rather than current wages because we also include lagged labor rather than current labor, due to our variable labor assumption. We further examine our instrumental variables assumptions in app. sec. C.1.12, where we also estimate a version of the model that does not rely on the agricultural price instrument and in which we also test other instruments using agricultural demand and supply shocks.

demand varies due to markup and markdown variation as well. The approach with input inversion can still be used when making additional parametric assumptions about the distribution of markups and markdowns. Another possibility is to impose more structure on the productivity transition process. Following Blundell and Bond (2000), we rely on the first-order autoregressive (AR[1]) structure of the productivity transition (2).[24] By taking ρ differences of equation (2), one can express the productivity shock v_{ft} as a function of estimable coefficients without having to invert the input demand function.[25]

We pursue this approach so as to avoid having to impose additional structure on the distribution of markups and markdowns across firms and over time. This comes at the cost of not allowing entry and exit of mines to be endogenous to their productivity level, contrary to Olley and Pakes (1996). However, as is often noted in the literature, the use of an unbalanced panel, in which one does not select negatively on market exit, already alleviates most concerns of selection bias.[26]

Rewriting the moment conditions from equation (16) and using lags of at most 1 year, the moment conditions are given by equation (17):[27]

$$\begin{aligned}\mathbb{E}[q_{ft} - \rho q_{ft-1} - \beta^0(1-\rho) - \beta^{\mathrm{l}}(l_{ft} - \rho l_{ft-1}) - \beta^{\mathrm{m}}(m_{ft} - \rho m_{ft-1}) \\ - \beta^{\mathrm{k}}(k_{ft} - \rho k_{ft-1}) | (l_{ft-1}, m_{ft-1}, k_{ft}, k_{ft-1}, w^{\mathrm{agri}}_{t-1})] = 0.\end{aligned} \tag{17}$$

We measure q_{ft} as the logarithm of annual coal production in metric tons at mine f during year t. Similarly, labor l_{ft} is measured as the logarithm of the average number of workers employed throughout the year, multiplied by the average number of days worked. Materials m_{ft} are measured as the logarithm of the "ordinary expenses" variable, which is reported in the data. The logarithm of the capital stock k_{ft} is constructed by using the perpetual inventory method on the "extraordinary expenses" category, which we describe in more detail in appendix section B.3. To estimate the production function using ordinary least squares (OLS), the logs of output, employment, material usage, and capital need to be observed. This reduces the sample size from 8,779 to 4,480 observations, as also explained in table B.6. For the generalized method of moments (GMM) estimator, the lagged values of these variables need to be observed as well. This additional sample restriction further decreases the number of observations

[24] In app. sec. C.1.7, we do a robustness check in which we set $\rho = 1$, rather than estimating ρ. In app. sec. C.1.9, we test for serial correlation in the productivity shocks v and also estimate a second-order autoregressive model (AR[2]) as an extension.

[25] An alternative is to estimate the output elasticities using a cost shares approach, rather than estimating the production function. Appendix sec. C.1.8 contains the estimates using this approach, which are of similar magnitudes as those in the main text.

[26] See Olley and Pakes (1996) and De Loecker et al. (2016).

[27] In theory, one could use more lags, but this further reduces the dataset, which is already small.

to 4,005.[28] We block-bootstrap the estimation procedure, taking draws by replacement within mines over time. We use 200 bootstrap draws. We sequentially estimate (i) the production function, (ii) markdowns and markups, and (iii) regressions of markdowns and markups on other variables within the same bootstrap iteration, in all the regressions that follow.

The production function estimates are in panel A of table 1. Column 1 reports the OLS estimates. We include these estimates merely as a comparison; we know they are biased due to the well-known simultaneity problem. Column 2 reports the GMM estimates that address the input simultaneity problem. Our model is overidentified, and, based on the Hansen *J*-test statistic, we cannot reject overidentifying restrictions. The output elasticity of labor β^{l} is estimated at 0.699, whereas the output elasticity of materials β^{m} is estimated at 0.222. These estimates confirm the historical record that Belgian coal mining was indeed very labor-intensive. The capital coefficient β^{k} is 0.153, and the serial correlation of productivity is 0.866. As usual, OLS overestimates the output elasticity of labor but underestimates the output elasticity of capital.

In column 3, we again use GMM to estimate the production function, but impose the RTS parameter $\varsigma \equiv \beta^{\mathrm{l}} + \beta^{\mathrm{m}} + \beta^{\mathrm{k}}$ to be equal to $\varsigma = 1.05$. The main reason to do so is that, in the full model—which does not impose any restrictions on RTS—the production function parameters are quite noisily estimated. Assuming mildly increasing RTS of 1.05 seems like a reasonable assumption given that the full model implies RTS of 1.07 and that prior coal mining production estimates for late-nineteenth-century Illinois coal mines deliver RTS at $\varsigma = 1.03$ (Rubens 2024). Appendix section C.1.2 contains the adapted moment conditions when imposing an RTS parameter and also carries out robustness tests for assuming different RTS parameters. Imposing the restriction of $\varsigma = 1.05$ leads to similar, but much more precisely estimated, output elasticities. In the rest of the paper, unless explicitly mentioned otherwise, we will continue to use the estimates of the full version of the model to maximize the generalizability of our model and to avoid the need for additional assumptions on the existence of RTS.

2. Labor Supply

Next, we estimate the market-level inverse labor supply function, equation (3) in logs, defining labor markets at the municipality-year level. We obtain market-level employment L_{it} by summing firm-level employment within each market, while the market-level average wage W^{l}_{it} is computed by taking the

[28] We discuss how the sample size is affected by conditioning on whether certain variables are observed for all regressions in app. sec. B.5.

TABLE 1
Model Estimates

	log(Output)		log(Output)		log(Output)	
	Est.	SE	Est.	SE	Est.	SE
	A. Production Function, log(Output)					
log(Labor) β^{l}	.794	.034	.699	.327	.661	.041
log(Materials) β^{m}	.275	.028	.222	.138	.237	.080
log(Capital) β^{k}	−.008	.140	.153	.075	.102	.088
Serial correlation TFP ρ			.866	.198	.853	.157
Method	OLS		GMM		GMM	
RTS	Free		Free		Fixed at 1.05	
R^2	.941		.938		.826	
Hansen J-test			2.34		2.72	
Hansen J-test p-value			.126		.255	
Number of firms	166		159		159	
Observations	4,480		4,005		4,005	
	B. Markdowns and Markups					
Median markdown	1.541	.193	1.680	.450	1.486	.330
Average markdown	1.676	.224	1.828	.491	1.616	.361
Median markup	.884	.112	.714	.494	.763	.287
Average markup	.946	.120	.764	.535	.816	.315
Method	OLS		GMM		GMM	
RTS	Free		Free		Fixed at 1.05	
	C. Labor Supply					
	log(Wage)		log(Wage)			
	Est.	SE	Est.	SE		
log(Employment)	.066	.006	1.009	.265		
Method	OLS		IV			
First-stage F-statistic			462			
Hansen J-test			5.92			
Hansen J-test p-value			.014			
Observations	1,990		1,990			
Firm-level elasticity	155.56		10.172			

Note.—Panels A and B are estimated at the firm-year level, and panel C is estimated at the market-year level. Standard errors (SEs) in panels A and B are block-bootstrapped with 200 iterations. Standard errors in panel C are estimated using the Driscoll and Kraay (1998) correction to allow for both cross-sectional (i.e., intratemporal) and intertemporal dependence, using the STATA command ivreg2,draay(2).

average of the firm wages, weighted by their employment shares within each market. As mentioned above, there is barely any within-municipality wage variation. Moreover, 90% of the workers did not commute more than 10 km from their home, as shown in figure D.7. This shows that most workers were employed within the boundaries of the village where they lived.

To identify the labor supply curve, we need labor demand shifters, as firms choose employment levels with knowledge of the latent market-level labor supply shifters $\nu_{\ell t}$. We rely on two labor demand shifters. First, we construct an indicator variable for the coal demand shock between 1871 and 1875 due to the aftermath of the Franco-Prussian War of 1870, which coincided with a peak in the international coal price as shown in figure 2. After the Franco-Prussian War, the French coal basin in Lorraine was annexed by Germany, which resulted in a sharp increase in the international coal price and hence in the demand for coal in the Liège and Namur coal basin. This "coal famine" of the early 1870s was exacerbated by cold winters and other reasons for rapid increases in consumption (Murray and Silvestre 2020, 688). This instrument is measured as a dummy indicating the years between 1871 up to and including 1875. Second, we include cartel membership during the cartel period as a demand shifter, given that the cartel decreased coal supply and hence labor demand for the cartel participants. This is measured as the interaction term of the cartel dummy with the postcartel period. We control for cartel membership and for the time dummy indicating the postcartel period. Conditioning on these instruments and on log employment and wages to be observed, the market-level sample size drops from 2,624 to 1,990 observations.

The estimates are in panel C of table 1. The market-level inverse elasticity of labor supply Ψ^{l} is estimated at 1.009. This implies that at a monopsonistic firm the marginal revenue product of labor is twice the wage, whereas it would be 10% above the wage at a firm with a labor market share of 10%. Converting this market-level inverse elasticity to a firm-level labor supply elasticity, as explained in appendix section A.4, implies an average firm-level elasticity of 10.172. This is of a similar order of magnitude as the average labor supply elasticity in current-day studies as surveyed in Sokolova and Sorensen (2021). Based on the Hansen *J*-test, we can reject overidentifying restrictions.

Again, we perform a wide range of robustness checks. In appendix section C.2.4, we allow for time-changing labor supply coefficients and also include a linear time trend. In appendix section C.2.5, we reestimate the model using different labor market definitions, as well as assess the potentially confounding effects of the expansion of the railroad network throughout the nineteenth century. In appendix section C.2.6, we change the time window over which the coal price shock instrument is defined to 1871–74 and 1871–76. In appendix section C.2.7, we compare our results against two separate model specifications that rely on only the price surge instrument and the cartel membership instrument, respectively. We prefer to keep both instruments as the main specification because this gives both intertemporal and cross-sectional variation in the instrument.

B. *Markdowns and Markups*

1. Wage Markdowns and Price Markups

Using the production function coefficients, we can now estimate coal price markups μ_{ft} and wage markdowns μ^{l}_{ft} following equation (13) and the right-hand side of equation (14), respectively. The log markdowns are observed for 4,702 observations. The estimated moments are in panel B of table 1. Taking our preferred specification that does not impose an RTS parameter, we obtain a median wage markdown of 1.680, which implies a markdown wedge of miner wages δ^{l}_{ft} of 40% below the marginal revenue product of labor. The average wage markdown is 1.828. Although both the median and average wage markdowns were not significantly different from 1 over the entire time period, there is an important fraction of firms and time periods for which wage markdowns are significantly above 1. We will assess drivers of this wage markdown heterogeneity across firms and time further below. Imposing an RTS parameter of 1.05 results in slightly lower markdown estimates of 1.486 and 1.616 at the median and on average, respectively. The standard errors on the markdown estimates reduce, even when normalizing to the median and average markdown levels, because the production function is estimated more precisely when imposing this RTS restriction.

In contrast to the wage markdown, the coal price markup was much lower. Using the full model, the price markup at the median firm was 0.714; the average was 0.764. Hence, coal prices are below marginal costs. This does not mean that firms were loss making, given that the total profit margin is the combined wage markdown and price markup. The joint markup $\mu^{\text{tot}} \equiv 1 + (\mu_{ft} - 1) + (\mu^{l}_{ft} - 1)$, which is the sum of the coal price markup and the wage markdown, is 1.44 at the median firm and 1.58 on average, which implies that these firms were making profits despite negative markups. The joint markup is negative for 13% of observations only.

Our low markup estimates suggest that coal mines had little market power downstream. This is no surprise, given that the relevant coal market size was much larger than Liège and Namur. Figure 2 shows that the coal price in Liège and Namur followed the international coal price up to 1897, which indicates that the firms in our dataset were price takers on the coal market. This is in line with recent historical research that has highlighted the increasing integration of the European coal market through the nineteenth century (Murray and Silvestre 2020). If the coal firms in the dataset were price takers on the coal market, this would imply that markup $\mu_{ft} = 1$, which cannot be rejected from our markup estimates. Our result of prices below marginal cost $\mu_{ft} < 1$, even if this finding is not significant, could be explained by monopsony power of coal buyers, such as large steel plants or railroad companies. If these industrial buyers have monopsony power over the coal mines, it is conceivable that they would use this power to push down coal prices to grasp the profit margins generated by monopsony power of the coal mines on the labor market.[29] Normally, monopsonistic buyers would not push prices below marginal

[29] This was also discussed in Rubens (2023b) in the context of Chinese tobacco markets.

costs because their suppliers would then exit the market. However, in our setting, coal firms do not exit the market when coal prices fall below marginal costs, because there is still the markdown wedge between marginal costs and input prices as an additional source of profits.

Taken together, the markdown and markup estimates above imply that coal firms mainly derived profits from market power on their labor markets, rather than on the coal market.[30] Still, equilibrium markdowns above 1 do not necessarily imply collusion: they could be due to noncollusive oligopsony power. In what follows, we will unpack the effects of collusion on the wage markdown, starting with a correlational analysis in the next subsection. As mentioned earlier, all estimates are derived from our preferred specification without assuming RTS, unless otherwise noted.

2. Evolution and Drivers of the Wage Markdown

Figure 3 plots the evolution of the wage markdown $\hat{\mu}^{l}_{ft}$ in all coal mines in Namur and Liège provinces between 1845 and 1913. Up to the 1870s, the median firm had a wage markdown ratio of around 1.5, which implies that wages were around a third below the marginal revenue product of labor. This ratio was relatively stable throughout the 1840s, 1850s, and 1860s. The average wage markdown, weighted by employment shares, was higher, around 1.75 on average.[31] During the late 1870s and 1880s, a long period of recession, median wage markdowns grew moderately to around 1.7. Despite short-run fluctuations, the wage markdown usually reverted to its long-term mean within 4–5 years.

Around 1900, there was a sharp increase in the wage markdown, both on average and at the median firm. The average wage markdown after 1897 was around 2.2, meaning that workers received less than 50% of their marginal revenue product. This wage markdown increase was persistent: there was no reversion to the pre-1897 steady-state level. The estimates in table 2 show that the increase in the wage markdown after 1897 was statistically significant. The wage markdown increase after 1897 does not reflect reallocation between firms but was the result of within-firm markdown growth. Figure D.11 compares the unweighted average wage markdown to the weighted average wage markdown, by employment usage. The unweighted average wage markdown grew by even more after 1897, which indicates that there was some reallocation away from the highest-markdown firms after 1897.

[30] Nonetheless, in app. sec. D.4, we find moderate positive effects of the 1897 cartel on the markups of its participants.

[31] Figure D.11 compares the unweighted and weighted markdown series, which up to the cartel period are very similar. Appendix sec. C.3.2 compares different weighting methods to construct aggregate markdowns.

FIG. 3.—Evolution of average and median wage markdowns, 1845–1913. This graph shows the evolution of the weighted average (by employment) markdown and median wage markdown in Liège and Namur coal mines from 1845 to 1913.

TABLE 2
MARKDOWNS: CORRELATIONS AND EVOLUTION

	log(Markdown)		log(Markdown)	
	Est.	SE	Est.	SE
	A. Markdown Correlations			
1(Employers' association)	.112	.052		
1(Cartel)	.080	.041		
1(1855 ≤ year < 1865)			−.021	.039
1(1865 ≤ year < 1875)			−.020	.038
1(1875 ≤ year < 1885)			.059	.045
1(1885 ≤ year < 1895)			.108	.047
1(1895 ≤ year < 1905)			.196	.045
1(1905 ≤ year < 1915)			.422	.054
Year fixed effects	Yes		No	
R^2	.094		.076	
Observations	4,432		4,705	
	B. Employers' Association, Pre- vs. Postcartel			
1(Employers' association)	.132	.042	−.058	.091
Period	1845–97		1898–1913	
R^2	.094		.130	
Observations	3,737		695	

NOTE.—Panels A and B are both estimated at the firm-year level. The reference category for the time dummies in panel A is the period between 1845–1859. Block-bootstrapped standard errors (SEs) are computed using 200 iterations.

What could explain the variation in wage markdowns across firms? The historical discussion in section II.D highlighted two key drivers. First, there was the pervasive nature of employers' associations throughout the nineteenth century. Based on internal communication by the union, we created a time-invariant variable indicating the union membership of each firm. A second big shift in the competitive environment of both coal and labor markets happened in 1897, when the coal cartel Syndicat des Charbonnages Liégeois was set up. The cartel statutes reveal which firms were part of said cartel.[32]

In column 1 of table 2, we compare markdowns across employers' association and cartel membership. Having to observe these membership statuses reduces the sample from 4,702, the sample on which markdowns are observed, to 4,429. We find that wage markdowns were 11.2% higher among employers' association members. This confirms anecdotal evidence of wage fixing through these employers' associations. Wage markdowns were also 8.0% higher for members of the coal cartel, but, given that the membership of the cartel and the employers' associations overlap, there is a possibility of multicollinearity here. Also, comparing wage markdowns at cartel and noncartel firms does not reveal the true effect of cartel membership on wage markdowns, as this variation could be due to a variety of markdown drivers. This again highlights the need for a more solid identification approach toward collusion.

In panel B of table 2, we compare the correlation between wage markdowns and employers' association membership between two time periods: the pre- and the postcartel period. The difference in wage markdowns between employers' association members and nonmembers that existed prior to 1897 entirely disappears after the introduction of the cartel in 1897. This suggests that the informal wage collusion that took place in employers' associations, which was not legally binding, was replaced as a driver of wage markdowns by the formal collusion through the coal cartel.

3. Markdown Heterogeneity

The homogeneous employers Cournot model has strong empirical implications for wage and markdown variation, which can be tested using our data and estimates. First, the Cournot model implies within-market markdown variation, whereas wages should be homogeneous. Moreover, in the absence of full collusion, wage markdowns should be higher for firms with high labor market shares, given that they face more inelastic firm-specific (residual) labor supply curves. Under full collusion, wage markdowns should be equalized within markets, and wage markdowns should no longer be increasing in firm size.

[32] For more information on the firm-level membership data, we refer to app. sec. B.2.

We test these implications using the markdown estimates from the production model. We regress the log wage markdown on the log labor market share in three specifications: one without any fixed effects, one including market fixed effects, and one including market × year fixed effects. The results can be found in the three sets of estimates in table 3, respectively. Panel A reports these correlations for all firms, panel B only for firms that are not part of the cartel, and panel C for the cartel firms. For the noncartel firms, there is quite some markdown variation within a given year and market: market × year fixed effects explain 55% of markdown variation. Moreover, there is a positive relationship between firm size, as measured by the labor market share, and markdowns, both with and without market × year fixed effects. However, when conditioning on the cartel members, we find that there is no longer a positive relationship between labor market shares and markdowns as soon as we control for market fixed effects. Although there is still some variation in wage markdowns within market-year cells for collusion firms, there is much less markdown heterogeneity than for noncartel firms. The latter is in line with the theory. The finding that markdowns are not exactly identical for cartel members could be due to imperfect discipline among the cartel members.

TABLE 3
Size-Markdown Correlations

	log(Markdown)					
	Est.	SE	Est.	SE	Est.	SE
	A. All Firms					
log(Labor market share)	.044	.001	.055	.003	.051	.004
Fixed effects	None		Market		Market × year	
R^2	.067		.192		.550	
Observations	4,671		4,671		4,671	
	B. Noncartel Firms					
log(Labor market share)	.037	.000	.053	.005	.065	.005
Fixed effects	None		Market		Market × year	
R^2	.046		.180		.561	
Observations	3,183		3,183		3,183	
	C. Cartel Firms					
log(Labor market share)	.043	.001	.008	.002	−.004	.002
Fixed effects	None		Market		Market × year	
R^2	.063		.188		.793	
Observations	1,472		1,472		1,472	

Note.—We regress log markdowns on the log labor market employment share at the firm-year level for all firms (panel A), firms outside the cartel (panel B), and firms in the cartel (panel C). We control for a linear time trend and either no, market, or market × year fixed effects. The sample sizes of panels B and C add up to 4,655 because the cartel information is unobserved for 16 observations. Standard errors (SEs) are block-bootstrapped with 200 iterations.

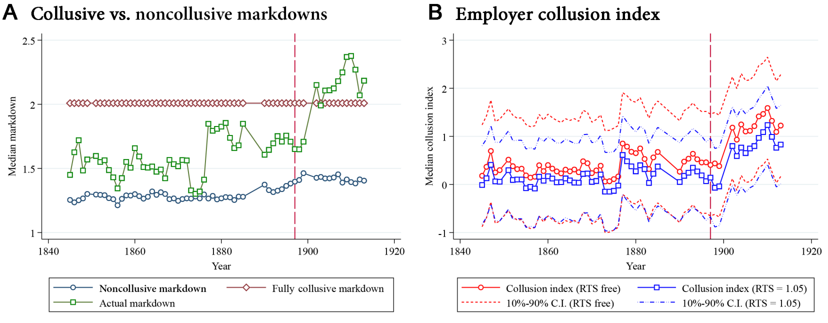

FIG. 4.—Employer collusion estimates, 1845–1913. *A*, The median markdown over time, along with the median of the lower and upper markdown bounds under no and full collusion. *B*, The median collusion index together with block-bootstrapped confidence intervals between 1845 and 1913. Two hundred bootstrap iterations are used.

C. *Employer Collusion*

1. Markdown Decomposition

We now decompose the estimated wage markdowns into a collusive and a noncollusive component and estimate the collusion index from equation (15). Figure 4*A* plots the evolution of actual wage markdowns and the collusive and noncollusive markdown bounds as defined in section III. The circles show the annual median of the lower markdown bound in the absence of collusion $\underline{\mu}^1$, the diamonds show the upper bound of markdowns under full wage collusion $\bar{\mu}^1$, and the squares show the estimated median markdowns, $\hat{\mu}^1_{ft}$, as estimated using the left-hand side of equation (14). Prior to the introduction of the cartel in 1897, the actual markdown lies above the noncollusive lower bound. This difference could be due to imperfect wage collusion devices such as the employers' associations.[33] After the introduction of the cartel in 1897, the estimated markdown level moves up to the fully collusive upper bound.

From 1870 to 1900, there was an increase in the median markdown level, but there was equally an increase in the noncollusive lower markdown bound. The moderate growth in markdowns prior to 1900 hence seems not to be related to wage collusion. However, around 1900, markdowns jump to the fully collusive upper bound for the wage markdown. Given that the noncollusive markdown does not grow after 1900, the vast increase in markdowns after the introduction of the coal cartel appears to have been entirely driven by wage collusion.

[33] This difference could also be due to any other deviation from the baseline Cournot model, such as search or adjustment frictions, firm differentiation, or dynamic labor supply. We examine input adjustment costs in sec. V.A and firm differentiation in app. sec. C.2.3.

2. Testing for Employer Collusion

We can now tackle the question of whether we are able to detect employer collusion during the cartel era without ex ante knowledge of said cartel. Figure 4*B* plots the evolution of median collusion by year for both our preferred specification that does not impose an RTS parameter (circles) and for the production function estimates that calibrate RTS at 1.05 (squares), along with 10%–90% confidence intervals. We find that the median markdown fluctuated around 0%–50% of the collusive markdown level up to 1900, but we cannot reject the null hypothesis of no wage collusion for any year up to 1900. From 1901, we can reject the null of no collusion for every year except 1903 at the 10% confidence level in the full model and from 1908 in the model that restricts RTS at 1.05. When imposing a 5% confidence level, which we do in figure D.12, we can equally reject the absence of collusion for 1905 in the full model and from 1908 in both the full and calibrated RTS versions of the model. The price data in figure 2 suggest that the collusive behavior within the cartel took off from 1904 onward, as this is the year in which Liège coal mine prices start moving toward the international coal price. Hence, the collusion estimates seem to be able to detect collusion due to the cartel, without requiring any a priori information about the cartel.[34]

D. Consequences of Employer Collusion

1. Counterfactual Setup

To assess the effects of the cartel on wages and employment, we need to close the model and solve for joint labor and product market equilibrium. Moving from a cartel to Cournot competition does not just change the wage markdown but also the marginal revenue product of labor. To solve for equilibrium, we assume symmetry within each labor market, meaning that in a labor market i with N_{it} firms, each firm has a labor market share of $1/N_{it}$. Although this symmetry assumption is clearly rejected by the data, we find that it provides a very close approximation to the truth when examining the market-level aggregate implications of collusion, as is the goal of the counterfactual. We show this in appendix section A.3. We also assume that all firms in a labor market have the same level of labor collusion and rely on the conduct parameter $\tilde{\lambda}_{it}$ as it was defined in equation (12). Using the symmetric firms assumption, the market-level parameter $\tilde{\lambda}_{it}$ can be written in function of the collusion index $\hat{\lambda}$ and of market structure:

[34] Admittedly, we did rely on cartel information as a demand shifter to estimate labor supply, but this is not strictly necessary. With the availability of demand shifters, one could identify collusion using our approach without requiring information about which firms are colluding or when.

$$\tilde{\lambda}_{it} = \frac{1}{N_{it}} + \hat{\lambda}_{it}\left(1 - \frac{1}{N_{it}}\right).$$

When member of a cartel, firms set $\tilde{\lambda}_{it} = 1$, as this implies full collusion. We examine two counterfactual scenarios to assess the effects of the cartel. First, we set $\tilde{\lambda}_{it} = 1/N_{it}$, which corresponds to the Cournot model. This is a world with a complete absence of employer collusion. Second, we set the conduct parameter to $\tilde{\lambda}_{it} = \bar{\lambda}$, with $\bar{\lambda}$ being the average collusion index in 1897, just before the cartel started. This counterfactual scenario assumes that the cartel did not happen but that firms continued to collude imperfectly, to the same extent as they did prior to the cartel.

To solve for equilibrium wages and employment, we also need to take a stance on the extent to which coal markets are competitive. We rely on two different models, which provide bounds for the cartel effects. In a first model, we assume that coal prices are exogenous to individual firms. This is equivalent to assuming that the coal market was transnational and that individual Belgian coal firms were all atomistic on this coal market. This assumption provides a lower bound on the wage and employment responses. In a second model, we impose Cournot competition on the coal market, which moves to perfect collusion as soon as the cartel enters. This second assumption implies that coal markets are the same as labor markets. As we discuss below, this provides an upper bound (in absolute value) for the wage and employment effects of the cartel. Given that the median markup estimate is not significantly above 1 and that the coal market was transnational, rather than local, we believe that the true effects of the cartel are closer to the lower bound than to the upper bound, at least for the median firm.

2. Model with Exogenous Coal Prices

We start with the model specification that assumes exogenous coal prices to each individual coal firm. Under this assumption, we do not need to impose and estimate a coal demand model. As derived in appendix A, solving the labor demand function derived from the production function (1) and the labor supply curve (3) delivers the following equilibrium wages and employment levels in each market i:

$$\begin{cases} W_{it}^{l} = \left(\dfrac{\beta^{l} R_{it} \nu_{it}^{(1/\Psi^{l})}}{1 + \Psi^{l}\tilde{\lambda}_{it}}\right)^{\Psi^{l}/(1+\Psi^{l})}; \\[2ex] L_{it} = \left(\dfrac{\beta^{l} R_{it}}{(1 + \Psi^{l}\tilde{\lambda}_{it})\nu_{it}}\right)^{1/(1+\Psi^{l})}. \end{cases}$$

Using these equilibrium expressions, we compute the counterfactual wage and employment levels under Nash-Cournot competition and under pre-1897 conduct. The cartel effects are summarized in panel A of table 4. Compared to a baseline model of Cournot competition on the labor market, the cartel decreased both wages and employment by around 10%. However, the collusion estimates from the previous section suggest that labor market competition was not Cournot prior to the cartel. If we compare the cartel to a baseline model in which labor market conduct remained constant at its 1897 average, we find that employment and wages decreased by 6%.

If coal prices were endogenous to individual coal firms, the counterfactual employment and wage effects of collusion would be larger, as collusion leads firms to internalize both the market-level labor supply and the market-level product demand curve. Hence, as we show in section IV.D.3, the exogenous coal price counterfactual constitutes a lower bound to the employment and wage effects of the cartel.

3. Model with Endogenous Coal Prices

Next, we extend the model to allow for endogenous coal prices. Now, we need to formulate and estimate a coal demand model as well. We impose equation (18) as the market-level coal demand curve, with a market-level inverse demand elasticity η and a market-level coal demand shifter ξ_i:

$$P_{it} = Q_{it}^{\eta}\xi_{it}. \tag{18}$$

We identify joint equilibrium on the labor and product market by solving the system of equations given by the labor supply curve (3), the production

TABLE 4
Effects of Employer Collusion

	Comparison: Cartel vs.	
	Cournot	Pre-1898 Conduct
	A. Exogenous Price	
Relative wage change	−.103	−.059
Relative employment change	−.102	−.059
	B. Endogenous Price	
Relative wage change	−.251	−.167
Relative employment change	−.249	−.166
Relative price change	.174	.100
Relative output change	−.283	−.195

Note.—Panel A summarizes the wage and employment effects of moving from the fully collusive coal cartel to either Cournot competition or to the estimated level of collusion prior of the cartel introduction, assuming exogenous coal prices. Panel B does the same for the model that allows for endogenous coal prices.

function (1), and the coal demand function (18). The equilibrium expressions for output, coal prices, employment, and wages are derived in appendix section A.5. We again assume symmetric firms within each market i and assume that the labor and product markets coincide. This implies a market share $1/N_{it}$ on both the coal and labor market. The conduct parameter $\tilde{\lambda}_{it}$ governs collusion both upstream and downstream. Given that the coal market is, in reality, broader than the municipality, this counterfactual most likely assumes too much market power on the product market and can hence be seen as an upper bound to the cartel effects on both labor and product market outcomes.

To carry out the endogenous coal price counterfactual, we need to estimate the coal demand function from equation (18). We estimate the coal demand function in appendix section D.5 using estimated mining productivity as a cost shifter, which delivers an estimate of $\eta = -0.383$. Also, we need to calibrate the unobserved intermediate input and capital prices W^m and W^k. We calibrate these (unobserved) input prices by targeting the distance between mean equilibrium output as predicted by our model and observed output.[35]

Using the model estimates and the equilibrium expressions for wages, prices, employment, and coal production, we again conduct the counterfactual exercise. The cartel effects are summarized in panel B of table 4. Compared to a baseline model of Cournot competition, the cartel decreased both wages and employment by 25%, compared to 10% in the exogenous prices model. Output shrank by 28% in response to the cartel, while prices increased by 17%. If we compare the cartel to a baseline model in which labor market conduct remained constant at its 1897 average, we find that employment and wages decreased by 17%, coal output decreased by 20%, and coal prices increased by 10%.

An important caveat for the counterfactual exercise above is that a certain degree of market power might be necessary to compensate fixed costs incurred by mining firms. A breakdown of the cartel could result in the exit of mining firms, given that they would no longer recover their fixed costs under the lower wage markdowns and, potentially, lower markups in the absence of the cartel.[36] We examine such endogenous exit in appendix section D.3.

V. Sensitivity Analysis

We conclude the empirical analysis by discussing three potentially confounding variables of our markdown estimates and hence of our collusion

[35] We cannot separately identify intermediate input prices from capital prices in this way, so we calibrate them to be identical.

[36] We find evidence for the cartel increasing markups in app. sec. D.4.

measure: adjustment frictions, factor-biased technological change, and the emergence of collective bargaining and unionization.

A. *Input Adjustment Costs*

Although labor markets were characterized by little firing and hiring costs from the employer side, as documented in section II.C, there could still be adjustment frictions that explain wedges between the marginal revenue product of inputs and input prices. Such frictions would be reflected in our markdown estimates: they are additional reasons for a wedge between the marginal revenue product of labor and wages. Also, inventories of intermediate inputs would invalidate our static input demand model and could explain short-run fluctuations in cost shares. Both these deviations from the static input demand model would threaten the identification of labor collusion: they would lead to wedges between the observed markdown and the labor supply elasticities unrelated to collusion. However, given that adjustment costs are by definition temporary, they should mainly affect cross-sectional variation in markdowns; they can explain neither the longer-term trends of our wage markdown and collusion estimates nor their correlation with the employer unions and cartels.

Moreover, we have direct evidence of the lack of adjustment frictions on labor and materials from the impulse-response function of the 1871 coal demand shock. We plot labor expenditure, intermediate input expenditure, and capital investment in the median mine around the 1871 demand shock in figure D.10. Labor and intermediate input expenditure increase immediately as the import price of coal increases, but capital investment lags by approximately 1 year. This evidence against adjustment costs on labor and intermediate inputs and for such costs on capital confirms the timing assumptions made for identifying the production function. The lack of adjustment costs on the variable inputs also shows that it is unlikely that our markdown estimates pick up input adjustment costs rather than monopsony power, which is important for the identification of collusion, as was explained above.

B. *Factor-Biased Technical Change*

Our markdown identification strategy relies on a Hicks-neutral production function. In the presence of directed technological change, factor-augmenting productivity levels are not separately identified from wage markdowns (Rubens 2023b). That would be problematic for our identification approach of collusion: the difference between the labor supply elasticities and the markdown estimates could then be due to directed technological change, rather than to collusion. Rubens (2023b) finds that, in the context of nineteenth-century US coal mining, coal cutting machines were a directed technology that changed the output elasticity of miners. However, as mentioned before, these machines were not adopted in Liège until 1908 and had limited use even then due to local coal veins being too narrow. Moreover, we highlight three facts in support of the Hicks-neutrality assumption made in the paper.

First, figure D.5*b* shows the evolution of total investment by Liège and Namur coal mines, in millions of BEF. The main peak in investment happened in the late 1870s, and it mainly resulted in increased installations of water pumps and the adoption of mechanical mine ventilation fans, which we present in figure D.5*a*. As was shown in figure 1*B*, the labor cost share did not persistently change between 1870 and 1890, despite the large increase in capital investment during the 1870s. If technological change was capital or materials biased, we would see a falling cost share of labor throughout this investment peak—unless the factor-biased effects of the capital investment were offset exactly by a simultaneous decrease in labor market power, which seems unlikely. Conversely, the decrease in the labor cost share after 1897 did not coincide with a large increase in capital investment, contrary to what we would expect if technological change was factor biased. There was an increase in the materials cost share after 1897, which shows that firms were substituting labor for materials. This is in line with the labor collusion model: as the marginal cost of labor increases because firms incorporate their effects on rival labor costs, firms substitute away from labor. Second, the correlation between our markdown estimate and the amount of horsepower for each of the three technology variables we observe is low: −0.012 for ventilation machines, 0.015 for water pumps, and 0.003 for locomotives. If these technologies were factor biased, they would correlate with our markdown estimates, as they would affect variable input cost shares. Third, we present an alternative production function specification that allows for interaction effects between capital and the variable inputs in appendix section C.1.3. This exercise confirms our finding that wage markdowns and collusion increased in 1897.

C. Unionization and Democratization

In this paper, we have focused on labor market collusion between employers. However, workers can also collude, for instance, through trade unions. Our focus on employer rather than employee collusion is due to the fact that trade unions struggled to make a significant impact in Belgium throughout the nineteenth and early twentieth centuries as worker collectives were heavily restrained by the legal framework (see section II.C). In the social movements of the 1880s and onward, coal mine workers were prominent participants, but they largely failed to materialize their demands. Although the coal sector was by far the biggest social battleground in terms of numbers of strikes and employees involved at the turn of the nineteenth century, the share of successful strikes from the perspective of the labor force was notably lower than the industry average, indicating a strong position of the employer (see fig. D.3). A reason for this can be found in the lack of centralized syndical actions, as the Belgian federation is considered to have been the "weak link in the international chain of mining syndicalism" (Michel 1977, 467). This was especially the case in the Liège coal basin, where the scattered and heterogeneous nature of local mining companies hindered the formation of collective action (Michel 1977, 470). If trade unions had been successful during the time period studied, this would have violated the assumption in the labor supply model that employers unilaterally choose employment and hence wages without bargaining with workers. However, changes in workers' bargaining power should be reflected in our cost-side markdown estimate, which does not impose a conduct assumption on the worker side. Given that higher bargaining power of unionized workers would lead to higher wages, this would negatively affect the cost-side markdown estimate and hence the employer collusion estimate.

One dimension in which the social movements of the final decades of the nineteenth century were successful was the demand for increased political participation. In appendix section C.3.3, we examine the extent to which democratization and the rise of the Belgian Socialist Party affects our results. Overall, we find little support for the hypothesis that the socialists' emergence on the political scene decreased employer market power and the scope of collusion in the short run, aligning with the historical record of the welfare state only gaining traction in the later stages of the twentieth century.

VI. Conclusions

In this paper, we examine the role of employer collusion in the exertion of labor market power. Building on prior production-cost-side approaches to markup and markdown identification, we propose a novel method to identify employer collusion using production and cost data. We use this approach to examine the extent to which wage markdown levels and growth during the Belgian industrial revolution was driven by collusion between employers. We estimate wage markdowns set by 227 firms between 1845 and 1913 and hence provide the first long-run view of how labor market competition evolved during the industrialization process. Our findings reveal that markdown levels were relatively stable throughout the nineteenth century but increased sharply around the turn of the century. We decompose these markdowns into a collusive and noncollusive component and use this to show that the rise of markdowns around 1900 was entirely driven by collusive behavior. This surge aligns with the introduction of the Belgian coal cartel in 1897, which we are able to identify without ex ante information about the cartel. Finally, we conduct a counterfactual exercise to quantify the effects of the 1897 coal cartel on employment and wages. We find that under this cartel, wages and employment were 10%–25% lower than they would be in Cournot competition. In comparison to the observed partially collusive conduct prior to 1897, the cartel depressed wages and employment by 6%–17%.

Our findings have two important implications. First, we find that collusive behavior can play an important role in shaping labor market power and wage growth, which calls for the incorporation of cooperative wage setting in empirical models of imperfectly competitive labor markets. Second, we find that downstream cartels can lead to significant losses in worker and consumer welfare, even if product markets are competitive. Hence, in settings with imperfectly competitive factor markets, antitrust policy should not be concerned only with addressing collusion on product markets but also on labor and other factor markets, as also argued by Naidu, Posner, and Weyl (2018). As an avenue for future research, we see much potential in the further investigation of specific types of collusive labor market practices besides overt wage fixing, such as tacit wage collusion, information sharing, and “no-poaching” agreements, all of these being practices that can be observed in both historical and current-day labor markets.

Data Availability

Code replicating the tables and figures in this article can be found in the Harvard Dataverse, https://doi.org/10.7910/DVN/FG1JSE (Delabastita and Rubens 2024).

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