Colluding Against Workers

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Abstract

Empirical models of labor market competition usually assume that employers set wages non-cooperatively, 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%.

JEL classification codes: N33, J42, L40

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1 Introduction

There are growing concerns about increasing levels of labor market power held by firms (Krueger, 2018; Manning, 2021; Sokolova & Sorensen, 2021). Whereas current empirical labor market models focus on many sources of imperfect competition, such as labor market frictions (Caldwell & Harmon, 2019), concentration (Schubert, Stansbury, & Taska, 2021), or employer differentiation (Card, Cardoso, Heining, & Kline, 2018), they usually assume non-cooperative 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 (Gibson, 2021, Krueger & Ashenfelter, 2022, Naidu, Posner, & Weyl, 2018, 597-598, U.S. Department of Justice, 2019) 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 non-cooperative 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

[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.

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 19th 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 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 micro-data 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 multi-product 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 non-collusive 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 non-collusive 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 onwards. 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% to 17% compared to the observed pre-cartel 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 % to 25%.

These results have external validity beyond the 19$^{\text{th}}$-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*, Friedrich Engels (1892, 241-260) lamented the "cheating" and "plundering" by the "coal kings", as British coal owners' associations actively fixed wages (Church, 1986, 651-674). 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 U.S. 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 U.S., and we know that collusion was not unique to coal firms but was also present in many other industries, like 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, & Setzler, 2022) or oligopsonistic competition (Berger, Herkenhoff, & Mongey, 2019; Azar, Berry, & Marinescu, 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 that both marginal costs and conduct are latent. Possible solutions are to identify shifts in collusion, rather than its level (Ciliberto & Williams, 2014), to rely on in-sample variation in ownership (Miller & Weinberg, 2017), or to find instruments that are orthogonal to affect only marginal costs but not conduct, or vice-versa (C. Michel & Weiergraeber, 2018; Backus, Conlon, & 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); Morlacco (2020); Brooks, Kaboski, Li, and Qian (2021); Mertens (2020); Rubens (2024, 2023b); Yeh, Macaluso, and Hershbein (2022). 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 anti-competitive 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 upon 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 (1776, 75) already highlighted the unequal position between employer and employee, remarking upon 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 (Jedwab, Johnson,

& Koyama, 2022; Ogilvie, 2019; Humphries & Schneider, 2019; Naidu & Yuchtman, 2018). Throughout the 19th 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 19th 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 U.S., which was documented in Murray and Silvestre (2020) for the coal industry and Lamoreaux (2019) respectively, 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 2 describes the historical setting of Belgian coal mining and presents the data. In Section 3, we present the empirical model of labor supply, demand, and conduct. In Section 4, 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 5 provides a range of robustness checks. Finally, Section 6 concludes.

2 Industry background and facts

2.1 Data

Annual inspection reports

Our main data source is a novel data set which 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. Hence, they form the main data set used in this paper.[2]

For the 227 firms in our data set, 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 work-

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

ers. The data reports expenditure on, literally, 'non-labor 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 B.3.

The *Administration* data comes 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 B.1.3.

Additional data sets

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, or not. Finally, we use the Consumer Price Index (CPI) of Segers (2003) and the extension thereof to 1845 using Scholliers' index (1995) to deflate all nominal variables in the data set.

We discuss how the sample size is affected by the conditioning on whether certain variables are observed or not in Appendix B.5, which explains the sample sizes in the different regression tables.

2.2 Coal demand and production

The industrialization of Belgium

Belgium's Industrial Revolution, the first on the Continent, started when Walloon entrepreneurs imitated British technological innovations during the 18th century. This is clearly illustrated by the case of the first Newcomen machine on the Continent, which was constructed in in Tilleur, near Liège, only eight years from its inception in 1712 (Lebrun, Bruwier, Dhont, & Hansotte, 1981, 263, 313). The macroeconomic effects of these innovations materialized during the following decades, with industrial production taking off primarily from the middle of the 19th century: during the 1850s and 1860s, Belgium became an economic powerhouse (Gadisseur, 1979; Pluymers, 1992). This growth trend continued into the age of globalization when technologically advanced firms fuelled strong export performance in coal-based sectors, such as metal and steel production (Huberman, Meissner, & Oosterlinck, 2017).

Coal industry

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 19th 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 its labor force active in the mines. We illustrate this local concentration of economic activity using 1896 community-level data in Figure D.4 in Appendix D.

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 between 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 only have access to the necessary data for these provinces. Liège and Namur together represented approximately 3 out of 10 coal workers in Belgium and 20 to 25% of Belgian coal production throughout the 19$^{\text{th}}$ century.[3] 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 non-ferrous metal manufacturers (10%) (De Leener, 1908).

The Belgian economy's reliance on coal also meant that the local coal industry grew in tandem with its booming industrial manufacturing sector. During the economic downturn of the 1870s, however, it became increasingly clear that the first signs of exhaustion of Belgian mines meant that domestic coal producers could not meet local demand. Increasing imports from France and Germany, however, meant that coal prices remained relatively stable at around 10 Belgian Francs (BEF) per ton until 1900, with sharp price fluctuations that quickly reverted to the mean. Nonetheless, after 1900, a prolonged increase in coal prices took place. As we will see below, this coincides with the emergence of coal cartels.

While coal can be considered a relatively homogeneous product, there is some differentiation in its volatile matter content, which determines its usage. Four coal types are distinguished in the data set based on volatile content percentiles: $13-18\%$ (*houille maigre sans flamme*, 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. Mines often extracted a combination of these coal types, which are a function of the geological characteristics of the mine's location.

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 (*abatteurs* or *ouvriers à veine*) with a pickaxe. Third, the lumps were hauled to the surface in containers or minecarts by mules and laborers, *hiercheurs*, often young children and women. Fourth, coal had to be sorted

[3] We refer to Appendix D.1 for more background information the Belgian coal industry.

from debris, which was done at the surface.

Throughout the sample period, there was extensive capital accumulation and mechanization. First, 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.[4] Two other forms of mechanization were, however, increasingly adopted during the 19th century. First, mechanical pumps were introduced to remove water from the mines. These were initially steam-powered but from 1893 onwards also electrically-powered (Gaier, 1988, 72). The usage of water pumps mainly increased during the 1870s. Second, steam-powered ventilation fans were introduced from the 1870s onwards to deal with sudden releases of firedamp. In contrast to the hauling process, coal cutting was mechanized very little in Liège and Namur throughout our sample period. Pneumatic coal cutting machines would only be implemented in Liège coal mining around 1908 and had little success because coal veins were too narrow to use cutting machines.[5] This contrasts with, for instance, the case of the U.S. where these cutting machines were readily adopted from 1882 onward (Rubens, 2024). We discuss the implications of potential factor-biased technical change on our model and results in Section 5.2.

2.3 Labor markets

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 19th 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, merely 1% of the population held voting rights. This pushed questions on topics such as worker rights and living conditions to the political periphery. Karl Marx, in a letter exchange with

[4] We show this in Figure D.5a in Appendix D.2.

[5] At the 1905 world 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).

Friedrich Engels, called Belgium "the snug, well-hedged, little paradise" of the capitalist (1985, 47).

Labor legislation had been drafted under French rule at the beginning of 19^{th} 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 19^{th} century. Belgian trade unions were only in the embryonic stages of their development in the 19^{th} 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, micro-evidence 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 to 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 nor were re-entrances into the profession of coal mining (Leboutte, 1988, 47-55).[6]

Output per worker and wages

Figure 1a 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

[6] Our baseline model in Section 3.2 does not incorporate cross-industry mobility. We extend our model to allow for this by including an outside option containing non-coal industries in Appendix C.2.3.

stalled despite increasing output 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 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.5b in Appendix D.2. 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 expound this model in Section 3.[7]

Figure 1b plots the median and weighted average cost share of labor over time, defined as total labor expenditure over total input expenditure.[8] Until the 1890s, the median cost share of labor was relatively stable, whereas the weighted average cost share grew, indicating reallocation of inputs towards 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 3 and examine this in further detail in Section 5.2.

2.4 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.

Employers' associations

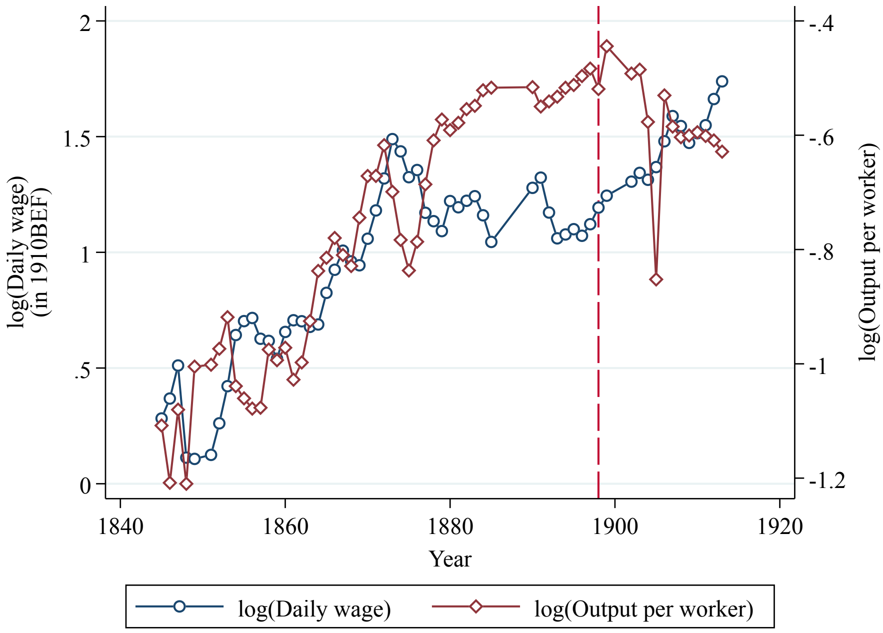
Similar to worker collusion, employer collusion on the labor market was illegal. However, the law stipulated much harsher punishment for worker collusion and included a vague and difficult-to-prove condition that employer collusion had to be "unjust" and "abusive" in order to be punishable (Stevens, 1998, 402). Labor market collusion

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

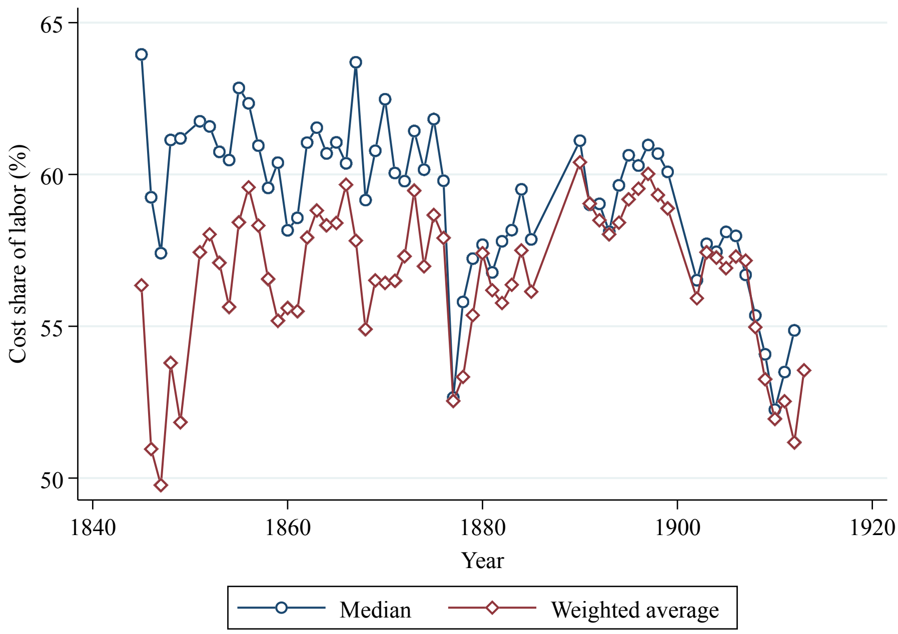
[8]We also refer to Table B.5 in Appendix B.4 which presents summary statistics on the cost shares and on other concession characteristics.

Figure 1: **Output per worker, wages, and cost shares in Liège- and Namur-based coal mining, 1845-1913**

(a) **Output per worker and wages**



(b) **Cost share of labor**



Notes: Figure (a) plots 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. Figure (b) plots the median and the average labor cost share of total expenditure, weighted by employment shares.

between employers was facilitated by employer unions or so-called 'employers' associations', a type of syndicate which was formed in many industries throughout the 19th

century.[9] 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.* 33% of firms in our data set 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 (...), 1872, 1887, 1889, 1896).

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 19th 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, primarily in the form of agreements on working hours, which are encapsulated in our employment variable (for examples, see De Leener, 1904, 122-126). Second, collusion was typically of an informal nature, as the Union did not impose formal quota 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 upon (Mottequin, 1973, 367). This anecdotal evidence indicates that multilateral agreements among 19th-century employers were

[9] 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.

rife and suggests that this collusive wage- or employment-setting behavior happened through employers' associations.

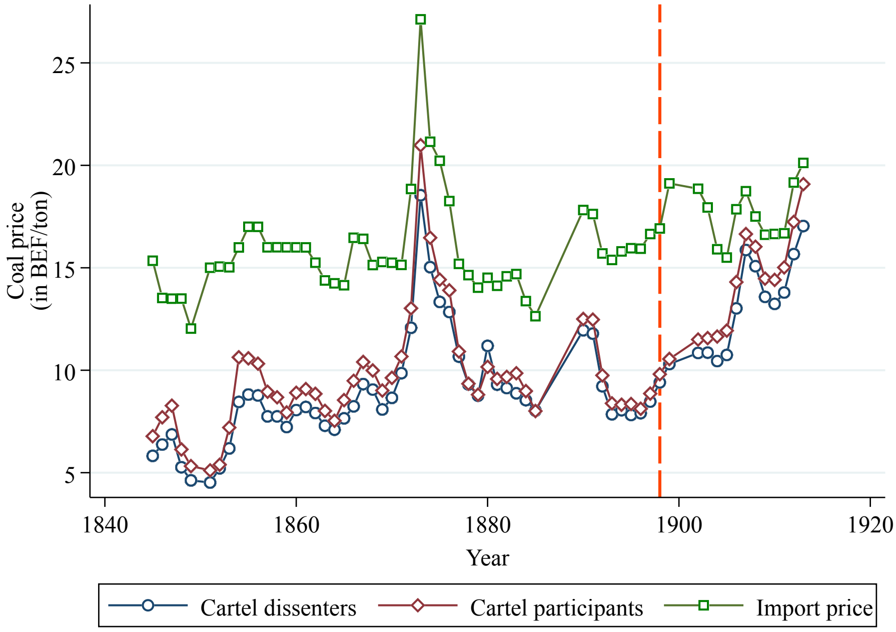
Coal cartels

As in many other industrializing countries, Belgian industries saw a strong increase in the number of (product market) cartels from the 1870s onwards. The number of official cartels in Belgium, which were legal and incorporated as firms, increased from 5 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* (SA), 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 twelve 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 50 BEF per excess ton (compared to an average price of 9.7 BEF per ton in 1898), while other violations of the cartel statutes were fined 1000 BEF. 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).

The effect of this cartel can be clearly seen by comparing the Liège coal price to the import price of coal in Belgium.[10] 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 towards imported coal. The cartel also seems

[10]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.

Figure 2: **Prices and the Liège coal cartel, 1845-1913**



Notes: The dashed vertical line represent the start of the coal cartel, the *Syndicat de Charbonnages Liégeois*.

to have had implications for the cost share of labor: as was shown in Figure 1b, 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.

3 Empirical model

In this section, we set up an empirical model of labor supply and demand in order 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.

3.1 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. We argue that this is innocuous because the caloric content of coal does not affect mining productivity.[11]

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}.

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

We specify a Cobb-Douglas production function in labor, capital, and materials, rather than specifying a production function with non-substitutable material inputs, because material inputs were to some extent substitutable.[12] For materials and labor, this can be illustrated with the example of mine tunnel excavation, an important activity in 19th-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.[13] We assume that the output elasticities $\boldsymbol{\beta}$ are constant over time, which we relax in Appendix C.1.4. In Appendix C.1.3, we extend the production model to a more flexible functional form by estimating a translog production function. In our baseline model, we do not impose any assumptions on the returns to scale in the production process. In Appendix C.1.2, we re-estimate the production function but impose a returns to scale parameter.

The Cobb-Douglas specification rules out factor-biased technological change. We see this as an innocuous assumption because, as was explained in Section 2.2, capital

[11] To assert this assumption, we regress the estimated 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 Appendix C.1.5. Appendix C.1.10 provides an extension to multi-product firms.

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

[13] 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).

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 unskill-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 5.2.

We assume that the total factor productivity transition is given by the first-order Markov process in Equation (2), with an unexpected productivity shock υ_{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 Appendix C.1.11.

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

We assume that both labor and intermediate inputs are variable and static inputs, meaning that they are not subject to adjustment frictions and only affect current profits. Capital is, in contrast, assumed to be a dynamic and fixed input: we assume capital investment is chosen one period in advance and affects both current and future profits, as capital does not depreciate immediately. We test these timing assumptions in Section 5.1 by looking at the impulse-response functions of the different inputs after the coal demand shock of 1871.

3.2 Labor supply

Labor and intermediate input supply

Firms face a labor supply function with an inverse firm-level elasticity $\psi^l_{ft} \equiv \frac{\partial W^l_{ft}}{\partial L_{ft}}\frac{L_{ft}}{W^l_{ft}}$. If firms are wage takers on the labor market, this implies that $\psi^l_{ft} = 0$, whereas labor market power implies $\psi^l_{ft} > 0$. We assume that firms are price-takers on their intermediate input markets, meaning that $\psi^m_{ft} \equiv \frac{\partial W^m_{ft}}{\partial M_{ft}}\frac{M_{ft}}{W^m_{ft}} = 0$. 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 C.1.6.

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 only increases the R^2 to 94%. If firms would be differentiated in terms of non-wage 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 C.2.1.[14] We provide a more formal test of employer differentiation in Appendix 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 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.[15] Wages W_{it}^l 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 non-frictional, heterogeneity in reservation wages across workers due to outside option differences would lead to an upward-sloping market-level labor

[14] Although a model of monopsonistic competition with amenities, such as a CES 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.

[15] We relax this assumption in Appendix C.2.4.

supply curve.

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

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'. The marginal revenue product of labor $MRPL_{ft}$ is defined in the usual way, $MRPL_{ft} \equiv \frac{\partial(P_{ft}Q_{ft})}{\partial L_{ft}}$.

$$\mu_{ft}^l \equiv \frac{MRPL_{ft}}{W_{ft}^l}$$

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:

$$\delta_{ft}^l \equiv \frac{MRPL_{ft} - W_{ft}^l}{MRPL_{ft}} = \frac{\mu_{ft}^l - 1}{\mu_{ft}^l}$$

Similarly, the coal price markup is defined as the ratio of the coal price over marginal costs, $\mu_{ft} \equiv \frac{P_{ft}}{MC_{ft}}$.

3.3 Employer behavior

We assume that firms choose variable input quantities in order 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 one unit at firm f.

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

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 non-poaching 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.[16]

We quantify the bounds of the wage markdown μ^l_{ft} under two different employer conduct assumptions: non-cooperative employment choices and perfect collusion.[17] In Appendix 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 non-cooperative baseline conduct than Cournot competition.

No collusion

In the absence of collusion, firms choose inputs in order 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 in order to minimize their current variable costs.

$$\min_{L_{ft},M_{ft}} \Big((L_{ft}W^l_{ft} + M_{ft}W^m_{ft}) - MC_{ft}\big(Q_{ft} - Q(L_{ft}, M_{ft}, K_{ft}, \Omega_{ft}; \boldsymbol{\beta})\big)\Big) \tag{5}$$

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

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

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

rewriting marginal costs MC_{ft} as the coal price over the markup $\mu_{ft} \equiv \frac{P_{ft}}{MC_{ft}}$ results in:

$$L_{ft}\frac{\partial W_{it}^{l}}{\partial L_{it}} + W_{it}^{l} = \frac{\partial Q_{ft}}{\partial L_{ft}}\frac{P_{ft}}{\mu_{ft}} \tag{6}$$

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 $s_{ft}^{l} \equiv \frac{L_{ft}}{L_{it}}$, 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 market share, as shown in Equation (7). We denote this markdown in the absence of collusion as $\underline{\mu}_{ft}^{l}$.

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

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).

$$\min_{L_{ft},M_{ft}} \Big(\sum_{g\in\mathcal{F}_{i(f)t}} \big(L_{gt}W_{gt}^{l} + M_{gt}W_{gt}^{m}\big) - MC_{ft}\big(Q_{ft} - Q(L_{ft}, M_{ft}, K_{ft}, \Omega_{ft}; \boldsymbol{\beta})\big)\Big) \tag{8}$$

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.

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

The resulting collusive markdown, which we denote $\overline{\mu}_{ft}^{l}$, 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 one, which rationalizes the collusive markdown (10) in comparison with the Cournot markdown (7).

$$\overline{\mu}^l_{ft} = 1 + \Psi^l \tag{10}$$

General formulation

In order 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 parametrizes 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). 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 in order to identify collusion.

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

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 υ_{ft}, firms choose their capital investment and decide whether to collude or not.[18] 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

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

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 C.2.3 for an alternative model with collusive wage-setting, rather than employment-setting.

3.4 Quantifying employer collusion

The model above shows that the labor supply elasticity allows us to identify the wage markdown μ^l_{ft} 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.[19] Substituting the output elasticity of labor β^l and the revenue share of labor $\alpha^l_{ft} \equiv \frac{W^l_{ft} L_{ft}}{P_{ft} Q_{ft}}$ 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).

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

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:

$$\mu_{ft} = \frac{\beta^m}{\alpha^m_{ft}} \tag{13}$$

Similarly to previous work (Yeh et al., 2022; Morlacco, 2020; Brooks et al., 2021), 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, $\frac{\beta^l \alpha^m_{ft}}{\beta^m \alpha^l_{ft}}$, is the cost-side markdown estimate, which does not depend on the conduct parameter $\tilde{\lambda}_{ft}$. The left-hand side term, $1 + \tilde{\lambda}_{ft}\Psi^l$, is the labor supply side markdown from the generalized Cournot model, which does depend on the conduct parameter.

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

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

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).

Conduct parameter

Rather than estimating the conduct parameter $\tilde{\lambda}_{ft} \in [s_{ft}^{l}, 1]$, 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 zero to one.[20] In the absence of collusion, $\hat{\lambda}_{ft} = 0$, whereas in a fully collusive market, $\hat{\lambda}_{ft} = 1$.

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

We operationalize this approach by following a step-wise approach. First, Section 4.1 presents the estimation of the production and labor supply functions. Second, in Section 4.2, we estimate and discuss the evolution of wage markdowns. Third, in Section 4.3, we quantify collusion and examine how it changed in response to the cartel. Finally, in Section 4.4, we carry out counterfactual exercises to examine the employment and wage effects of collusion.

[20]It is easy to show that $\hat{\lambda}_{ft} = \frac{\tilde{\lambda}_{ft} - s_{ft}^{l}}{1 - s_{ft}^{l}}$.

4 Identification, estimation, and results

4.1 Labor demand and supply

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 in order 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 υ_{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, 23). Negative shocks to agricultural wages hence should have acted as positive labor supply shocks to coal mines. We include lagged agricultural wages in Belgium, as measured by Segers (2003, 622-623), 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.[21] In Appendix Table D.4 of Appendix D.6, 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:

$$\mathbb{E}\Big[\upsilon_{ft}|(l_{fr-1}, m_{fr-1}, k_{fr}, w_{r-1}^{agri})\Big]_{r\in[2,\ldots,t]} = 0 \qquad (16)$$

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

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 υ_{ft} using the productivity law of motion (Olley & Pakes, 1996; Levinsohn & Petrin, 2003; Ackerberg et al., 2015). This approach hinges on productivity being the only latent, serially correlated input demand shifter. However, input 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 AR(1) structure of the productivity transition (2).[22] By taking ρ differences of Equation (2), one can express the productivity shock υ_{ft} as a function of estimable coefficients without having to invert the input demand function.

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.[23]

Rewriting the moment conditions from Equation (16) and only using the lags up to one year, the moment conditions are given by Equation (17).[24]

$$\mathbb{E}\Big[q_{ft} - \rho q_{ft-1} - \beta^0(1-\rho) - \beta^l(l_{ft} - \rho l_{ft-1}) - \beta^m(m_{ft} - \rho m_{ft-1}) - \beta^k(k_{ft} - \rho k_{ft-1}) \\ |(l_{ft-1}, m_{ft-1}, k_{ft}, k_{ft-1}, w_{t-1}^{agri})\Big] = 0 \quad (17)$$

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

[22]In Appendix C.1.7 we do a robustness check in which we set $\rho = 1$, rather than estimating ρ. In Appendix C.1.9, we test for serial correlation in the productivity shocks υ and also estimate an AR(2) model as an extension.

[23]See Olley and Pakes (1996) and De Loecker, Goldberg, Khandelwal, and Pavcnik (2016).

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

constructed by using the perpetual inventory method on the 'extraordinary expenses' category, which we describe in more detail in Appendix B.3. In order to estimate the production function using OLS, the logs of output, employment, material usage, and capital need to be observed. This reduces the sample size from 8779 to 4480 observations, as also explained in Table B.6 in Appendix B.5. For the GMM estimator, the lagged values of these variables need to be observed as well. This additional sample restriction further decreases the number of observations to 4005. 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 Table 1a. The first column reports the OLS estimates, as a comparison, whereas the second column reports the GMM estimates, which are used in the remainder of the paper. Our model is overidentified, and, based on the Hansen J-test statistic, we cannot reject over-identifying restrictions. The output elasticity of labor β^l is estimated to be 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. As usual, OLS overestimates the output elasticity of labor but underestimates the output elasticity of capital. We estimate the serial correlation of productivity to be 0.866. In Appendix C.1.8, we estimate the output elasticities using a cost shares approach, rather than estimating the production function. This approach results in production function coefficients of similar magnitudes.

Our production function parameters are quite noisily estimated. In Appendix C.1.2, we re-estimate the model but calibrate the returns to scale parameter $\varsigma = \beta^l + \beta^m + \beta^k$ to predetermined values. Doing so leads to much more precisely estimated output elasticities. As long as returns to scale are (modestly) increasing, we obtain very similar findings in this extension compared to the main model.

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

Table 1: **Model estimates**

Panel A: Production function		log(Output)		log(Output)	
		Est.	S.E.	Est.	S.E.
log(Labor)	β^l	0.794	0.034	0.699	0.327
log(Materials)	β^m	0.275	0.028	0.222	0.138
log(Capital)	β^k	-0.008	0.140	0.153	0.075
Serial correlation TFP	ρ	.	.	0.866	0.198
Method		OLS		GMM	
R-squared		.941		.938	
Hansen J-test				2.34	
Hansen J-test p-value				.126	
No. firms		166		159	
Observations		4480		4005	

Panel B: Markdowns/markups	Wage markdown		Price markup	
	Est.	S.E.	Est.	S.E.
Median	1.680	0.450	0.714	0.494
Average	1.828	0.491	0.764	0.535
Weighted average	1.802	0.594	0.726	0.546
Markdown/markup wedge, δ	0.392	0.593	-0.427	0.526

Panel C: Labor supply	log(Wage)		log(Wage)	
	Est.	S.E.	Est.	S.E.
log(Employment)	0.066	0.006	1.009	0.265
Method	OLS		IV	
First-stage F-statistic			462	
Hansen J-test			5.92	
Hansen J-test p-value			.014	
Observations	1990		1990	
Firm-level elasticity	155.56		10.172	

Notes: Panels A-B are estimated at the firm-year level, panel C is at the market-year level. Standard errors (S.E.) in panels A-B are block-bootstrapped with 200 iterations. S.E.s in panel C are estimated using the Driscoll and Kraay (1998) correction, to allow for both cross-sectional (i.e. intra-temporal) and inter-temporal dependence, using the STATA command `ivreg2, draay(2)`.

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 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 10km from their home, as shown in Figure D.7 in Appendix D.2. This shows that most workers were employed within the boundaries of the village where they lived.

In order 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, which coincided with a peak in the international coal price as shown in Figure 2. After the Franco-Prussian war of 1870, 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 & 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 post-cartel period. We control for cartel membership and for the time dummy indicating the post-cartel period. Conditioning on these instruments and on log employment and wages to be observed, the market-level sample size drops from 2624 to 1990 observations.

The estimates are in Table 1c. 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 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 over-identifying restrictions.

Again, we perform a wide range of robustness checks. In Appendix C.2.4, we allow for time-changing labor supply coefficients and also include a linear time trend. In Appendix C.2.5, we re-estimate the model using different labor market definitions, as well as assess the potentially confounding effects of the expansion of the railroad network throughout the 19th century. In Appendix C.2.6, we change the time window over which the coal price shock instrument is defined to 1871-1874 and 1871-1876. In Appendix C.2.7, we compare our results against two separate model specifications that rely only on the price surge instrument and on the cartel membership instrument, respectively. We prefer to keep both instruments as the main specification because this gives both inter-temporal and cross-sectional variation in the instrument.

4.2 Markdowns and markups

Wage markdowns and price markups

Using the production function coefficients, we can now estimate coal price markups μ_{ft} and wage markdown μ^l_{ft} following Equation (13) and the right-hand side of Equation (14), respectively. The log markdowns are observed for 4702 observations. The estimated moments are in Table 1b. At the median firm, the wage markdown is 1.680, which implies a markdown on miner wages of 40%. The average wage markdown is 1.802 when weighting by employment usage and 1.828 when taking the unweighted average. The median markdown wedge δ^l_{ft} is 39.2%. Although the median, average, and weighted average wage markdown was not significantly different from one over the entire time period, there is an important fraction of firms and time periods for which wage markdowns are significantly above one, which implies the exertion of oligopsony power. We will assess drivers of this wage markdown heterogeneity across firms and time further below.

In contrast to the wage markdown, the coal price markup was much lower. The price markup was at the median firm 0.714, on average 0.764, and weighted by employment usage 0.726. 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 $\mu^{tot} \equiv 1 + (\mu_{ft} - 1) + (\mu^l_{ft} - 1)$, which is the sum of the coal price markup and the wage markdown, is 1.58 on average and 1.44 at the median firm, which implies that these firms were making profits despite negative markups. The joint markup is negative for 12% 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 has shown that the coal price in Liège and Namur followed the international coal price up to 1897, which indicates that the firms in our data set were price takers on the coal market. This is in line with recent historical research that has highlighted the increasingly integrated nature of the European coal market throughout the 19$^{\text{th}}$ century (Murray & Silvestre, 2020). If the coal firms in the dataset were price takers on the coal market, this would imply a markup of one $\mu_{ft} = 1$, 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 in order to grasp the profit margins generated by monopsony power of the coal mines on the labor market.[25] Normally, monopsonistic buyers would not push prices below marginal 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.[26] Still, equilibrium markdowns above one do not necessarily imply collusion: they could be due to non-collusive 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.

Evolution and drivers of the wage markdown

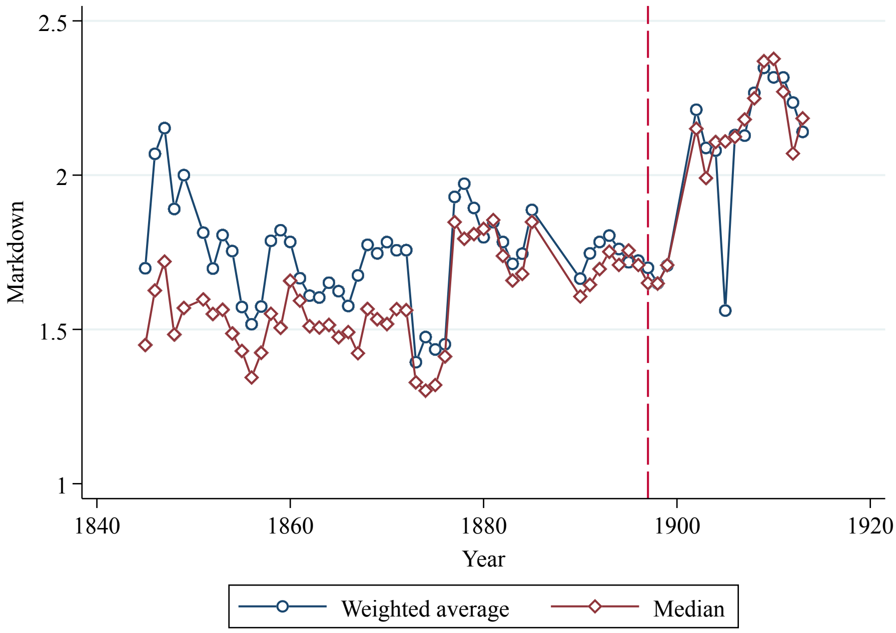
Figure 3 plots the evolution of the wage markdown $\hat{\mu}^l_{ft}$ in all coal mines in Namur and Liège provinces between 1845 and 1913. Up to the 1870s, the median firm had a wage

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

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

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.[27] 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 four to five years.

Figure 3: **Evolution of the average and median wage markdown, 1845-1913**



Notes: This graph shows the evolution of the weighted average (by employment) and median wage markdown in Liège and Namur coal mines from 1845-1913.

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 in Appendix D.6 compares the unweighted average wage markdown to

[27] Figure D.11 in Appendix D.6 compares the unweighted and weighted markdown series, which up to the cartel period are very similar. Appendix C.3.2 compares different weighting methods to construct aggregate markdowns.

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.

What could explain the variation in wage markdowns across firms? The historical discussion in Section 2.4 highlighted two key drivers. First, there was the pervasive nature of employers' associations throughout the 19$^{\text{th}}$ 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.[28]

In the first column of Table 2, we compare markdowns across employers' association and cartel membership. Having to observe these membership statuses reduces the sample from 4702, the sample on which markdowns are observed, to 4429. 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 concern of multicollinearity here. Also, comparing wage markdowns at cartel and non-cartel members does not reveal the true effect of the cartel on wage markdowns, as this variation could be due to a variety of markdown drivers. This highlights, again, the need for a more solid identification approach towards collusion.

In Table 2b, we compare the correlation between wage markdowns and employers' association membership between two time periods: the pre- and the post-cartel period. The difference in wage markdowns between employers' association members and non-members 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.

[28] For more information on the firm-level membership data, we refer to Appendix B.2.

Table 2: **Markdowns: correlations and evolution**

Panel A: Markdown correlations	log(Markdown)		log(Markdown)	
	Est.	S.E.	Est.	S.E.
1(Employers' Association)	0.112	0.052		
1(Cartel)	0.080	0.041		
1(1855<Year<1865)			-0.021	0.039
1(1865<Year<1875)			-0.020	0.038
1(1875<Year<1885)			0.059	0.045
1(1885<Year<1895)			0.108	0.047
1(1895<Year<1905)			0.196	0.045
1(1905<Year<1915)			0.422	0.054
Year FE	Yes		No	
R-squared	.094		.076	
Observations	4432		4705	
Panel B: Employers' assoc.: pre- vs. post-cartel	log(Markdown)		log(Markdown)	
	Est.	S.E.	Est.	S.E.
1(Employers' Association)	0.132	0.042	-0.058	0.091
Time period	1845-1897		1898-1913	
R-squared	.094		.130	
Observations	3737		695	

Notes: Panels A-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 (S.E.) are computed using 200 iterations.

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.

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-by-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 non-cartel 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 when including market-year fixed effects and when not doing so. 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 non-cartel 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.

4.3 Employer collusion

Markdown decomposition

We now decompose the estimated wage markdowns into a collusive and a non-collusive component and estimate the collusion index from Equation (15). Figure 4a plots the evolution of actual wage markdowns and the collusive and non-collusive markdown bounds as defined in Section 3. The blue circles are the annual median of the lower markdown bound in the absence of collusion, $\underline{\mu}^l$, the red diamonds are the upper bound of markdowns under full wage collusion, $\overline{\mu}^l$, and the green squares are the estimated median markdowns, $\hat{\mu}^l_{ft}$, 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 non-collusive lower bound. This difference could be due to imperfect wage collusion devices

Table 3: **Size-markdown correlations**

Panel A: All firms	log(Markdown)					
	Est.	S.E.	Est.	S.E.	Est.	S.E.
log(Labor market share)	0.044	0.001	0.055	0.003	0.051	0.004
Fixed effects	None		Market		Market × Year	
R-squared	.067		.192		.550	
Observations	4671		4671		4671	
Panel B: Non-cartel firms	log(Markdown)					
	Est.	S.E.	Est.	S.E.	Est.	S.E.
log(Labor market share)	0.037	0.000	0.053	0.005	0.065	0.005
Fixed effects	None		Market		Market × Year	
R-squared	.046		.180		.561	
Observations	3183		3183		3183	
Panel C: Cartel firms	log(Markdown)					
	Est.	S.E.	Est.	S.E.	Est.	S.E.
log(Labor market share)	0.043	0.001	0.008	0.002	-0.004	0.002
Fixed effects	None		Market		Market × Year	
R-squared	.063		.188		.793	
Observations	1472		1472		1472	

Notes: 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 add of panels B and C add up to 4655 because the cartel information is unobserved for 16 observations. Standard errors (S.E.) are block-bootstrapped with 200 iterations.

such as the employers' associations.[29] 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 non-collusive 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 non-collusive markdown does not grow after 1900, the vast increase in markdowns after the introduction of the coal cartel appears to

[29]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 in Section 5.1 and firm differentiation in Appendix C.2.3.

have been entirely driven by wage collusion.

Testing for employer collusion

An interesting question which we can tackle now, is whether we are able to detect collusion on wages during the cartel era without ex-ante knowledge of said cartel. Figure 4b plots the evolution of median collusion by year, along with confidence intervals. We find that the median markdown fluctuated around 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 onwards, we can reject the null of no collusion for every year except 1903 at the 10% confidence level. At the 5% confidence level, we can reject the absence of collusion for 1904 and in between 1906 and 1910. The price data in Figure 2 suggests that the collusive behavior within the cartel took off from 1904 onwards, as this is the year in which Liège coal mine prices start moving towards 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.[30]

4.4 Consequences of employer collusion

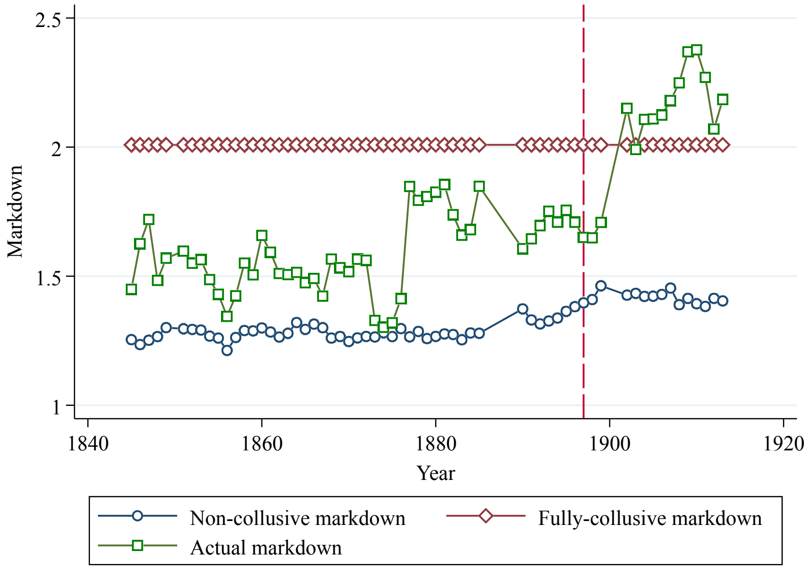
Counterfactual set-up

In order 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. In order 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 A.3. We also assume that all firms in a labor market have the same level of labor collusion and rely on the

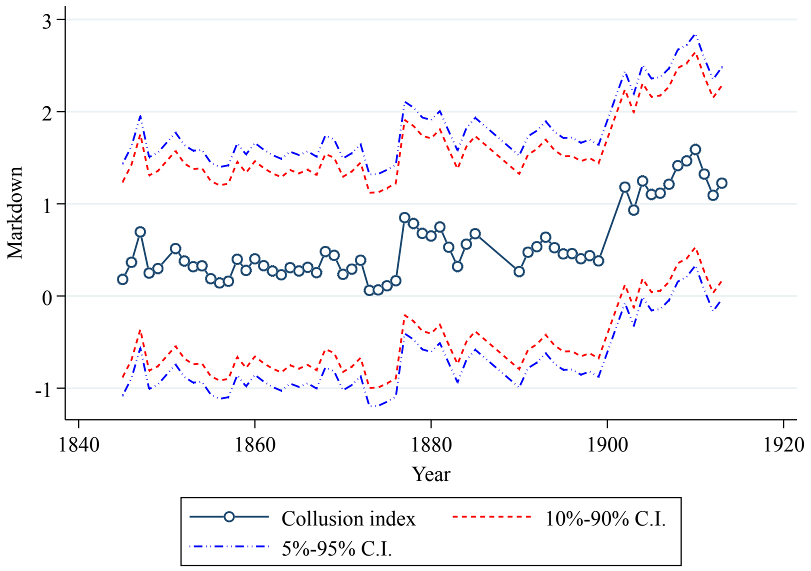
[30] Admittedly, we did rely on cartel information as a demand shifter to estimate labor supply, but this is not strictly necessary. With the availability of demand shifters, one could identify collusion using our approach without requiring information about which firms are colluding, or when.

Figure 4: **Employer collusion estimates, 1845-1913**

(a) **Collusive vs. non-collusive markdowns (median)**



(b) **Median employer collusion index**



Notes: Figure (a) plots the median markdown over time, along with the median of the lower and upper markdown bounds under no and full collusion. Figure (b) plots the median collusion index together with block-bootstrapped confidence intervals between 1845-1913. 200 bootstrap iterations are used.

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

When member of a cartel, firms set $\tilde{\lambda}_{it} = 1$, as this implies full collusion. We examine two counterfactual scenarios in order 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.

In order 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 one 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.

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:

$$\begin{cases} W^l_{it} &= \Big(\dfrac{\beta^l R_{it} \nu_{it}^{\frac{1}{\Psi^l}}}{1+\Psi^l \tilde{\lambda}_{it}}\Big)^{\frac{\Psi^l}{1+\Psi^l}} \\ L_{it} &= \Big(\dfrac{\beta^l R_{it}}{(1+\Psi^l \tilde{\lambda}_{it})\nu_{it}}\Big)^{\frac{1}{1+\Psi^l}} \end{cases}$$

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 the next paragraph, the exogenous coal price counterfactual constitutes a lower bound to the employment and wage effects of the cartel.

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 function (1), and the coal demand function (18). The equilibrium expressions for output, coal prices, employment, and wages are derived in Appendix 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 $\frac{1}{N_{it}}$ 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.

In order 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 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.[31]

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 whereas 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%.

Table 4: **Effects of employer collusion**

Panel A: Exogenous price	Comparison of cartel to:	
	Cournot	Pre-1898 conduct
Relative wage change	-0.103	-0.059
Relative employment change	-0.102	-0.059
Panel B: Endogenous price	Comparison of cartel to:	
	Cournot	Pre-1898 conduct
Relative wage change	-0.251	-0.167
Relative employment change	-0.249	-0.166
Relative price change	0.174	0.100
Relative output change	-0.283	-0.195

Notes: 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.

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

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

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.[32] We examine such endogenous exit in Appendix D.3.

5 Sensitivity analysis

We conclude the empirical analysis by discussing three potentially confounding variables of our markdown estimates, and, hence, of our collusion measure: adjustment frictions, factor-biased technological change, and the emergence of collective bargaining and unionization.

5.1 Input adjustment costs

Although labor markets were characterized by little firing and hiring costs from the employer side, as documented in Section 2.3, 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 cannot explain 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 by looking at 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 in Appendix D.6. Labor and intermediate input expenditure increase immediately as the import price of

[32] We find evidence for the cartel to increase markups in Appendix D.4.

coal increases, but capital investment lags by approximately one year. This evidence for the lack of adjustment costs on labor and intermediate inputs, and for the existence of adjustment 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.

5.2 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 19$^{\text{th}}$-century U.S. coal mining, coal cutting machines were a directed technology, which changed the output elasticity of miners. However, as mentioned before, these machines were not adopted in Liège until 1908 and only had limited use overall 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.5b in Appendix D.2 shows the evolution of total investment by Liège and Namur coal mines, in millions BEF. The main peak in investment happened in the late 1870s, and it mainly resulted in the increased installations of water pumps and the adoption of mechanical mine ventilation fans which we presented in Figure D.5a. As was shown in Figure 1b, the labor cost share did not persistently change between 1870 and 1890, despite the large upshoot 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, except if the factor-biased effects of the capital investment would be exactly offset 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, in 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 C.1.3. This exercise confirms our finding that wage markdowns and collusion increased in 1897.

5.3 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 19th and early 20th centuries as worker collectives were heavily restrained by the legal framework (see Section 2.3). 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 19$^{\text{th}}$ 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 Figure D.3 in Appendix D.1). 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" (J. 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 (J. Michel, 1977, 470). If trade unions had been successful during the time period studied, this would have violated the labor supply model imposed, which assumes that employers unilaterally choose employment and, hence, wages without bargaining with the 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 19$^{\text{th}}$ century were successful was the demand for increased political participation. In Appendix 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 20$^{\text{th}}$ century.

6 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 1845-1913 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 19th century but increased sharply around the turn of the century. We decompose these markdowns into a collusive and non-collusive 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% to 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% to 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 just be concerned with addressing collusion on product markets but also on labor and other factor markets, as also argued by Naidu et al. (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.

References

Ackerberg, D. A., Caves, K., & Frazer, G. (2015). Identification properties of recent production function estimators. *Econometrica*, *83*(6), 2411-2451.

Administration des Mines. (1831–1933). *Inventaire des archives de la deuxième inspection générale des mines: Liège (1831–1933).* Brussels: State Archives in Belgium, Brussels. (BE-A0510.254, Series 101–124 & 179–204)

Administration des Mines. (1896–1913). *Annales des mines de Belgique.* Brussels: Ministère de l'Industrie et du Travail.

Allen, R. C. (2009). *The British Industrial Revolution in global perspective.* Cambridge: Cambridge University Press.

Azar, J. A., Berry, S. T., & Marinescu, I. (2022). *Estimating labor market power* (Working paper). National Bureau of Economic Research.

Backus, M., Conlon, C., & Sinkinson, M. (2021). *Common ownership and competition in the ready-to-eat cereal industry* (Working paper). National Bureau of Economic Research.

Benkard, C. L. (2000). Learning and forgetting: The dynamics of aircraft production. *American Economic Review*, *90*(4), 1034–1054.

Berger, D. W., Herkenhoff, K. F., & Mongey, S. (2019). *Labor market power* (Working Paper). National Bureau of Economic Research.

Berry, S. (1994). Estimating discrete-choice models of product differentiation. *The RAND Journal of Economics*, 242–262.

Berry, S., Eizenberg, A., & Waldfogel, J. (2016). Optimal product variety in radio markets. *The RAND Journal of Economics*, *47*(3), 463–497.

Blomme, J. P. (1992). *The economic development of Belgian agriculture, 1880-1980. A quantitaitve and qualitative analysis.* Leuven: Leuven University Press.

Blundell, R., & Bond, S. (2000). GMM estimation with persistent panel data: An application to production functions. *Econometric Reviews*, *19*(3), 321–340.

Boal, W. M. (1995). Testing for employer monopsony in turn-of-the-century coal mining. *The RAND Journal of Economics*, 519–536.

Bresnahan, T. F. (1987). Competition and collusion in the American automobile industry: The 1955 price war. *The Journal of Industrial Economics*, *35*(4), 457–482.

Bresnahan, T. F., & Reiss, P. C. (1991). Entry and competition in concentrated markets. *Journal of Political Economy*, *99*(5), 977–1009.

Brooks, W. J., Kaboski, J. P., Li, Y. A., & Qian, W. (2021). Exploitation of labor? Classical monopsony power and labor's share. *Journal of Development Economics*, *150*, 102627.

Buyst, E. (forthcoming). Changes in the occupational structure of Belgium: New estimates for the 1846–1910 period. In O. Saito & L. Shaw-Taylor (Eds.), *Occupational structure, industrialization and economic growth in a comparative perspective.* Cambridge: Cambridge University Press.

Caldwell, S., & Harmon, N. (2019). *Outside options, bargaining, and wages: Evidence from coworker networks* (Working paper). MIT.

Capitaine, F. (1858). *Essai biographique sur Henri Joseph Orban.* Liège: J.-G. Carmanne Imprimeur.

Card, D., Cardoso, A. R., Heining, J., & Kline, P. (2018). Firms and labor market inequality: Evidence and some theory. *Journal of Labor Economics*, *36*(S1), S13–S70.

Caulier-Mathy, N. (1971). *La modernisation des charbonnages Liégeois pendant la première moitié du XIXe siècle: Techniques d'exploitation* (Vol. 192). Paris: Société d'Édition Les Belles Lettres.

Church, R. (1986). *History of the British coal industry. Volume 3. 1830-1913: Victorian pre-eminence.* Oxford: Clarendon Press.

Ciliberto, F., & Williams, J. W. (2014). Does multimarket contact facilitate tacit collusion? Inference on conduct parameters in the airline industry. *The RAND Journal of Economics*, *45*(4), 764–791.

Degrève, D. (1982). *Le commerce extérieur de la Belgique, 1830-1913-1939: Présentation critique des données statistiques* (Vol. 1b). Brussels: Palais des Académies.

Delabastita, V., & Goos, M. (2022). *Does technological progress equal wage progress? 19th-century technological change, real wage growth and wage inequality* (Working paper). KU Leuven.

De Leener, G. (1904). *Les syndicats industriels en Belgique* (2nd ed.). Brussels: Misch et Thron.

De Leener, G. (1908). *Étude sur le marché charbonnier Belge.* Brussels: Misch et Thron.

De Leener, G. (1909). *L'organisation syndicale des chefs d'industrie: Étude sur les syndicats industriels en Belgique.* Brussels: Misch et Thron.

De Loecker, J., Goldberg, P. K., Khandelwal, A. K., & Pavcnik, N. (2016). Prices, markups, and trade reform. *Econometrica*, *84*(2), 445-510.

De Loecker, J., & Scott, P. T. (2016). *Estimating market power: Evidence from the US brewing industry* (Working Paper). National Bureau of Economic Research.

De Loecker, J., & Warzynski, F. (2012). Markups and firm-level export status. *American Economic Review*, *102*(6), 2437–71.

Delrée, H., & Linard de Guertechin, A. (1963). Esquisse historique de la législation et de l'Administration des Mines. *Annales des Mines de Belgique*(1), 45–59.

Demeur, A. (1878). *Les sociétés commerciales de la Belgique: Années 1876, 1877, 1878.* Brussels: Chez l'Éditeur.

Dhyne, E., Petrin, A., Smeets, V., & Warzynski, F. (2022). *Theory for extending single-product production function estimation to multi-product settings* (Working Paper). National Bureau of Economic Research.

Dobbelaere, S., & Mairesse, J. (2013). Panel data estimates of the production function and product and labor market imperfections. *Journal of Applied Econometrics*, *28*(1), 1–46.

Drèze, G. (1905). *Le livre d'or de l'Exposition Universelle et Internationale de 1905: Histoire complète de l'exposition de Liège* (Vol. 2). Liège: Imp. Aug. Bénard.

Driscoll, J. C., & Kraay, A. C. (1998). Consistent covariance matrix estimation with spatially dependent panel data. *The Review of Economics and Statistics*, *80*(4), 549–560.

Dubois, G. (1960). *Enquête sur la structure et les activités des associations professionnelles.* Liège: Institut de Sociologie de l'Université de Liège.

Eizenberg, A. (2014). Upstream innovation and product variety in the U.S. home PC market. *Review of Economic Studies*, *81*(3), 1003–1045.

Engels, F. (1892). *The condition of the working-class in England in 1844: With preface written in 1892.* London: Swan Sonnenschein & Co.

Fishback, P. V. (1992). *Soft coal, hard choices: The economic welfare of bituminous coal miners, 1890-1930.* Oxford: Oxford University Press.

Gadisseur, J. (1979). *Le produit physique de l'économie Belge 1831-1913: Présentation critique des données statistiques* (Unpublished doctoral dissertation). Université de Liège, Liège.

Gaier, C. (1988). *Huit siècles de houillerie Liégeoise: Histoire des hommes et du charbon à Liège.* Liège: Editions du Perron.

Gallardo-Albarrán, D., & de Jong, H. (2021). Optimism or pessimism? A composite view on English living standards during the Industrial Revolution. *European Review of Economic History*, *25*(1), 1–19.

Geerkens, É., Leboutte, R., & Péters, A. (2020). Le travail des ouvriers mineurs en Belgique (ca 1830-1930). *Revue du Nord*(2), 289–309.

Gibson, M. (2021). *Employer market power in Silicon Valley* (Working Paper). IZA.

Huberman, M., Meissner, C. M., & Oosterlinck, K. (2017). Technology and geography in the Second Industrial Revolution: New evidence from the margins of trade. *The Journal of Economic History*, *77*(1), 39–89.

Humphries, J., & Schneider, B. (2019). Spinning the industrial revolution. *The Economic History Review*, *72*(1), 126–155.

Jedwab, R., Johnson, N. D., & Koyama, M. (2022). The economic impact of the Black Death. *Journal of Economic Literature*, *60*(1), 132-78.

Krueger, A. B. (2018). Reflections on dwindling worker bargaining power and monetary policy. In *Luncheon address at the Jackson Hole Economic Symposium* (Vol. 24).

Krueger, A. B., & Ashenfelter, O. (2022). Theory and evidence on employer collusion in the franchise sector. *Journal of Human Resources*, *57*(S), S324–S348.

Kurgan-van Hentenryk, G., & Puissant, J. (1990). Industrial relations in the Belgian coal industry since the end of the nineteenth century. In G. D. Feldman & K. Tenfelde (Eds.), *Workers, owners and politics in coal mining: An international comparison of industrial relations* (pp. 203–270). Oxford: Berg Publishers.

Kurgan-Van Hentenryk, G., Puissant, J., & Montens, V. (1996). *Dictionnaire des patrons en Belgique: Les hommes, les entreprises, les réseaux.* Brussels: De Boeck Université.

Lamadon, T., Mogstad, M., & Setzler, B. (2022). Imperfect competition, compensating differentials, and rent sharing in the US labor market. *American Economic Review*, *112*(1), 169–212.

Lamoreaux, N. R. (2019). The problem of bigness: From Standard Oil to Google. *Journal of Economic Perspectives*, *33*(3), 94–117.

Laureyssens, J. (1975). *Industriële naamloze vennootschappen in België 1819-1857* (Vol. 78). Leuven: Nauwelaerts.

Leboutte, R. (1988). *Le livret d'ouvrier dans la province de Liège: Une source méconnue en histoire sociale. Présentation et premier résultats d'exploitation.* Liège: Editions du Musée de la Vie Wallone.

Leboutte, R. (1991). Mortalité par accident dans les mines de charbon en Belgique aux XIXe-XXe siècles. *Revue du Nord*, *73*(293), 703–736.

Lebrun, P., Bruwier, M., Dhont, J., & Hansotte, G. (1981). *Essai sur la révolution industrielle en Belgique: 1770-1847.* Brussels: Palais des Académies.

Lefèvre, P. (2004). L'organisation des patrons charbonniers montois de 1830 à 1870. In K. Bertrams & S. Jaumain (Eds.), *Patrons, gens d'affaires et banquiers. Hommages à Ginette Kurgan-van Hentenryk* (pp. 129–140). Brussels: Livre Timperman.

Leo XIII. (1891). *Rerum novarum.* `https://www.vatican.va/content/leo-xiii/en/encyclicals/documents/hf_l-xiii_enc_15051891_rerum-novarum.html`. (Accessed: 05-08-2022)

Levinsohn, J., & Petrin, A. (2003). Estimating production functions using inputs to control for unobservables. *The Review of Economic Studies*, *70*(2), 317–341.

Loots, F. (1936). Les mouvements fondamentaux des prix de gros en Belgique de 1822 à 1913. *Bulletin de l'Institut des Sciences Économiques*, *8*(1), 23–47.

Luyten, D. (1995). *Sociaal-economisch overleg in België sedert 1918.* Brussels: VUB Press.

Mahaim, E. (1911). Les ouvriers mineurs abonnés aux chemins de fer en Belgique. *Annales des Mines de Belgique*, *16*, 69-115.

Manning, A. (2021). Monopsony in labor markets: A review. *ILR Review*, *74*(1), 3–26.

Martins, P. S. (2020). *What do employers' associations do?* (Working paper No. 13705). IZA Institute of Labor Economics.

Marx, K., & Engels, F. (1985). *Marx & Engels collected works: Volume 21 Marx and Engels 1867–1870.* London: Lawrence & Wishart.

Mertens, M. (2020). Labor market power and the distorting effects of international trade. *International Journal of Industrial Organization*, *68*(102562), 1-16.

Michel, C., & Weiergraeber, S. (2018). *Estimating industry conduct in differentiated products markets* (Working paper). Universitat Pompeu Fabra.

Michel, J. (1977). Un maillon plus faible du syndicalisme minier: La fédération nationale des mineurs Belges avant 1914. *Revue Belge de Philologie et d'Histoire*, *55*(2), 425–473.

Miller, N. H., & Weinberg, M. C. (2017). Understanding the price effects of the MillerCoors joint venture. *Econometrica*, *85*(6), 1763–1791.

Mokyr, J. (1976). *Industrialization in the Low Countries, 1795-1850.* London: Yale University Press.

Morlacco, M. (2020). *Market power in input markets: Theory and evidence from French manufacturing* (Working paper). University of Southern California.

Mottequin, P. (1973). *Réunions du comité des directeurs des travaux des charbonnages du Couchant de Mons, patronnées par la Société Générale (1848-1876).* Leuven: Éditions Nauwelaerts.

Murray, J. E., & Silvestre, J. (2015). Small-scale technologies and European coal mine safety, 1850–1900. *The Economic History Review*, *68*(3), 887–910.

Murray, J. E., & Silvestre, J. (2020). Integration in European coal markets, 1833–1913. *The Economic History Review*, *73*(3), 668–702.

Naidu, S., Posner, E. A., & Weyl, G. (2018). Antitrust remedies for labor market power. *Harvard Law Review*, *132*, 536–601.

Naidu, S., & Yuchtman, N. (2018). Labor market institutions in the gilded age of American economic history. In L. P. Cain, P. V. Fishback, & P. W. Rhode (Eds.), *The Oxford handbook of American economic history.* Oxford: Oxford University Press.

Office du Travail. (1896a). *Recensement général des industries & des métiers (31 octobre 1896): Volume II: Répartion par commune des industries et des métiers: Hainaut, Liège, Limbourg, Luxembourg, Namur.* Brussels: Hayez.

Office du Travail. (1896b). *Recensement général des industries & des métiers (31 octobre 1896): Volume I: Répartion par commune des industries et des métiers: Anvers, Brabant, Flandre Occidentale, Flandre orientale.* Brussels: Hayez.

Office du Travail. (1903). *Statistique des grèves en Belgique: 1896-1900.* Brussels: J. Lebègue & Compagnie.

Office du Travail. (1907). *Statistique des grèves en Belgique: 1901-1905.* Brussels: J. Lebègue & Compagnie.

Office du Travail. (1911). *Statistique des grèves et lock-out en Belgique: 1906-1910.* Brussels: J. Lebègue & Compagnie.

Office du Travail du Belgique. (1896–1913). *Revue du travail.* Brussels: Ministère de l'Industrie et du Travail.

Ogilvie, S. (2019). *The European guilds: An economic analysis.* Princeton: Princeton University Press.

Olley, G. S., & Pakes, A. (1996). The dynamics of productivity in the telecommunications equipment industry. *Econometrica*, *64*(6), 1263–1297.

O'Rourke, K. H. (1997). The European grain invasion, 1870–1913. *The Journal of Economic History*, *57*(4), 775–801.

Orr, S. (2022). Within-firm productivity dispersion: Estimates and implications. *Journal of Political Economy*, *130*(11), 2771–2828.

Pakes, A. (2010). Alternative models for moment inequalities. *Econometrica*, *78*(6), 1783–1822.

Pluymers, B. (1992). *De Belgische industriële produktie 1811-1846: Reconstructie van een databank van de fysieke produktie en de bruto-toegevoegde waarde* (Working paper). KU Leuven.

Recueil Financier. (1893). *Le recueil financier annuel: 1893-1894.* Brussels: l'Industrie.

Roussille, N., & Scuderi, B. (2023). *Bidding for talent: Equilibrium wage dispersion on a high-wage online job board* (Working Paper). MIT.

Rubens, M. (2023a). Management, productivity, and technology choices: Evidence from U.S. mining schools. *RAND Journal of Economics*, *51*(1), 165-186.

Rubens, M. (2023b). Market structure, oligopsony power, and productivity. *American Economic Review*, *113*(9), 2382-2410.

Rubens, M. (2024). *Labor market power and factor-biased technology adoption* (Working paper). UCLA.

Scholliers, P. (1995). A century of real industrial wages in Belgium, 1840–1939. In

P. Scholliers & V. Zamagni (Eds.), *Labour's reward: Real wages and economic change in 19th- and 20th-century Europe* (pp. 106–137). Aldershot: Edward Elgar Publishing.

Schubert, G., Stansbury, A., & Taska, B. (2021). *Employer concentration and outside options* (Working paper). Harvard University.

Segers, Y. (2003). *Economische groei en levensstandaard: Particuliere consumptie en voedselverbruik in België, 1800-1913.* Leuven: Leuven University Press.

Smith, A. (1776). *An inquiry into the nature and causes of the wealth of nations.* Chicago: University Of Chicago Press. (1976 reprint)

Sokolova, A., & Sorensen, T. (2021). Monopsony in labor markets: A meta-analysis. *ILR Review*, *74*(1), 27-55.

Statistique de la Belgique. (1858). *Mines, minières, usines minéralurgiques et machines à vapeur: 1851 à 1855.* Brussels: Ministre de l'Intérieur.

Stengers, J. (2004). Histoire de la législation électorale en Belgique. *Revue belge de Philologie et d'Histoire*, *82*(1), 247–270.

Stern, D. I. (2011). Elasticities of substitution and complementarity. *Journal of Productivity Analysis*, *36*, 79–89.

Stevens, F. (1998). Het coalitieverbod in België (1795–1866). In *Liber amicorum Roger Blanpain* (pp. 395–413). Bruges: Die Keure.

Syverson, C. (2004). Market structure and productivity: A concrete example. *Journal of Political Economy*, *112*(6), 1181–1222.

Treuren, L. (2022). *Wage markups and buyer power in intermediate input markets* (Working paper DPS22.06). KU Leuven.

Union des charbonnages (...). (1869–1913). *Bulletin de l'Union des charbonnages, mines et usines métallurgiques de la province de Liège.* Liège: Imprimerie H. Vaillant-Carmanne.

U.S. Department of Justice. (2019). *Antitrust division Spring update 2019: No-poach approach.* `https://www.justice.gov/atr/division-operations/division-update-spring-2019/no-poach-approach`.

Van den Eeckhout, P. (2005). Van werkboekje tot arbeidscontract. De negentiende-eeuwse arbeidsrelaties revisited. *Journal of Belgian History*, *35*(2-3), 153–200.

Van Overfelt, W., Annaert, J., De Ceuster, M., & Deloof, M. (2009). Do universal banks create value? Universal bank affiliation and company performance in Belgium, 1905–1909. *Explorations in Economic History*, *46*(2), 253–265.

Vanthemsche, G. (1983). De Belgische overheid en de kartels tijdens het interbellum: Situering en analyse van de wetgeving op de verplichte kartelvorming. *Revue belge de Philologie et d'Histoire*, *61*(4), 851–894.

Vanthemsche, G. (1995). De geschiedenis van de Belgische werkgeversorganisaties:

Ankerpunten en onderzoekshorizonten. *NEHA-Bulletin*, *9*(1), 3–20.

Verboven, F., & Yontcheva, B. (2022). *Private monopoly and restricted entry: Evidence from the notary profession* (Working paper). KU Leuven.

Wibail, A. (1934). L'évolution économique de l'industrie charbonnière Belge depuis 1831. *Bulletin de l'Institut des Sciences Économiques*, *6*(1), 3–30.

Yarmie, A. H. (1980). Employers' organizations in mid-Victorian England. *International Review of Social History*, *25*(2), 209–235.

Yeh, C., Macaluso, C., & Hershbein, B. (2022). Monopsony in the U.S. labor market. *American Economic Review*, *112*(7), 2099-2138.

Appendices

Table of contents

A Derivations and theory

A.1 Markups and markdowns in the general model

In the main text, we derive an upper and lower bound for the wage markdown and price markup under the assumption of no and perfect collusion. In this Appendix, we derive the markup and markdown expressions in general. Taking the first-order condition of the cost minimization problem (4) for labor results in:

$$W^l_{ft} + \frac{\partial W^l_{ft}}{\partial L_{ft}} L_{ft} + \sum_{g \neq f} \lambda_{fgt} \frac{\partial W^l_{gt}}{\partial L_{ft}} L_{gt} = \frac{\partial Q_{ft}}{\partial L_{ft}} MC_{ft}$$

Using the definitions of the own- and cross-firm labor supply elasticities, $\psi^l_{ft} = \frac{\partial W^l_{ft}}{\partial L_{ft}} \frac{L_{ft}}{W^l_{ft}}$ and $\psi^l_{fgt} = \frac{\partial W^l_{gt}}{\partial L_{ft}} \frac{L_{ft}}{W^l_{gt}}$, and rearranging terms, we obtain:

$$W^l_{ft}(1 + \psi^l_{ft} + \sum_{g \neq f} \lambda_{fgt} \psi^l_{fgt} \frac{L_{gt} W^l_{gt}}{L_{ft} W^l_{ft}}) = \frac{\partial Q_{ft}}{\partial L_{ft}} MC_{ft}$$

Given that MC_{ft} denotes marginal costs and using the markup formula $\mu_{ft} = \frac{P_{ft}}{MC_{ft}}$, we have that:

$$W^l_{ft}(1 + \psi^l_{ft} + \sum_{g \neq f} \lambda_{fgt} \psi^l_{fgt} \frac{L_{gt} W^l_{gt}}{L_{ft} W^l_{ft}}) = \frac{\partial Q_{ft}}{\partial L_{ft}} \frac{P_{ft}}{\mu_{ft}}$$

Rearranging terms gives the following expression:

$$W^l_{ft} L_{ft}(1 + \psi^l_{ft} + \sum_{g \neq f} \lambda_{fgt} \psi^l_{fgt} \frac{L_{gt} W^l_{gt}}{L_{ft} W^l_{ft}}) = \frac{\partial Q_{ft}}{\partial L_{ft}} \frac{L_{ft}}{Q_{ft}} \frac{P_{ft} Q_{ft}}{\mu_{ft}}$$

Finally, using the output elasticity of labor definition $\theta^l_{ft} = \frac{\partial Q_{ft}}{\partial L_{ft}} \frac{L_{ft}}{Q_{ft}}$ and the revenue share of labor $\alpha^l_{ft} = \frac{W^l_{ft} L_{ft}}{P_{ft} Q_{ft}}$ results in:

$$\mu_{ft} = \frac{\theta^l_{ft}}{\alpha^l_{ft}(1 + \psi^l_{ft} + \sum_{g \in \mathcal{F}_{i(f)t} \setminus f} \lambda_{fgt} \psi^l_{fgt} \frac{L_{gt} W^l_{gt}}{L_{ft} W^l_{ft}})}$$

Similar to the derivation in the main text, 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 have that:

$$W^m_{ft} = \frac{\partial Q_{ft}}{\partial M_{ft}} MC_{ft}$$

Similar to the two last steps of the derivation above, we are able to obtain the markup formula derived from material usage:

$$\mu_{ft} = \frac{\theta^m_{ft}}{\alpha^m_{ft}}$$

A.2 Conduct identification in the general model

As in the main text, comparing the cost-side and labor supply-side markdowns allows identifying conduct. We illustrate this here for the general model, rather than for the Cournot model used in the main text. Dividing the markup derived from the labor first-order condition by the markup derived from the materials first-order condition yields Equation (A.1), which is the general version of Equation (14). The left-hand side is the markdown based on the labor supply estimates, which is a function of the conduct parameter matrix Λ_t. The right-hand side is the cost-side markdown estimate, which is obtained independently of conduct. By equating both sides of this equation, it becomes possible to identify either the conduct matrix Λ_t, plausibly under some additional symmetry assumptions, or a collusion index which is a function of the conduct matrix, as we have done in the main text.

$$1 + \psi^l_{ft} + \sum_{g \in \mathcal{F}_{i(f)t} \setminus f} (\lambda_{fgt} \psi^l_{fgt} \frac{L_{gt} W^l_{gt}}{L_{ft} W^l_{ft}}) = \frac{\theta^l_{ft} \alpha^m_{ft}}{\theta^m_{ft} \alpha^l_{ft}} \tag{A.1}$$

A.3 Symmetry assumption in the counterfactuals

In the counterfactual exercise in the main text, we assumed that all firms have equal labor market shares. In this appendix, we show that the market-level counterfactuals under this assumption are a close approximation of the true market-level counterfactuals under asymmetric market shares.

The counterfactual exercise consists of comparing market-level aggregates of employment, wages, output, and prices between the cartel and Cournot competition. Under the cartel, the market shares of individual firms are irrelevant, as they all charge an identical markdown $1+\Psi$. However, asymmetric market shares do matter for aggregate outcomes in the Cournot counterfactual because the aggregate markdown differs depending on how different market shares are. The aggregate distortion from monopsony power in a market i at time t that consists of a set of firms $\mathcal{F}_{it}$ is measured by the size-weighted aggregate markdown μ^{l*}_{it}, as defined in Equation (A.2a).

$$\mu^{l*}_{it} \equiv \sum_{g \in \mathcal{F}_{it}} \mu^{l}_{gt} s^{l}_{gt} \tag{A.2a}$$

Substituting the Cournot markdown expression into Equation (A.2a) reveals that the aggregate markdown in Cournot competition is equal to the market-level inverse labor supply elasticity Ψ times the Herfindahl index, as shown in Equation (A.2b) .

$$\mu^{l*}_{it} = \sum_{g \in \mathcal{F}_{it}} s^{l}_{gt}(1+\Psi s^{l}_{gt}) = 1 + \Psi \sum_{g \in \mathcal{F}_{it}} (s^{l}_{gt})^2 \tag{A.2b}$$

Under the symmetric firms assumption, the aggregate markdown expression simplifies to the market-level supply elasticity divided by the number of firms in a market N_{it}. We denote this aggregate markdown under the symmetry assumption as μ^{l*}_{it}, which is given by Equation (A.2c).

$$\mu^{l*}_{it} = \sum_{g \in \mathcal{F}_{it}} s_{gt}(1+\Psi s_{gt}) = 1 + \frac{\Psi}{N_{it}} \tag{A.2c}$$

The symmetric aggregate markdown is smaller than the aggregate markdown under asymmetry. Hence, the estimated difference between the collusion and Cournot aggregate outcomes is larger when imposing symmetric market shares compared to asymmetric market shares. However, in practice, the market-level aggregate markdown under the symmetry assumption is very closely aligned to the one derived under the observed asymmetric market shares. The average market-level markdown in Cournot competition under the symmetric market shares model is 1.543, whereas it is 1.524 under asymmetric market shares. The median market-level markdowns are 1.504 in the symmetric model and 1.514 in the asymmetric model. Hence, the market-level counterfactual effects estimated in the main text should be closely aligned with the counterfactual effects under heterogeneous market shares.

A.4 Labor supply elasticities

In the main text, we estimated the market-level inverse labor supply elasticity Ψ. This elasticity can be inverted to a regular market-level labor supply elasticity, Equation (A.3a).

$$\frac{\partial L_{it}}{\partial W^l_{it}}\frac{W^l_{it}}{L_{it}} = \frac{1}{\Psi^l} \tag{A.3a}$$

Similarly, the firm-level labor supply elasticity in the Cournot model is obtained by inverting the inverse firm-level labor supply elasticity, as in Equation (A.3b).

$$\frac{\partial L_{ft}}{\partial W^l_{it}}\frac{W^l_{it}}{L_{ft}} = \frac{1}{\Psi^l s^l_{ft}} \tag{A.3b}$$

A.5 Equilibrium expressions for the counterfactuals

A.5.1 Model with exogenous prices

We look for equilibrium wages and employment subject to the production function being (1) and the labor supply curve (3), assuming exogenous coal prices. We assume N_{it} symmetric firms in each labor market i, meaning that each firm f has a labor market share $s_{ft} = \frac{L_{it}}{N_{it}}$. We denote revenues as $R_{ft} \equiv Q_{ft}P_{ft}$. The first-order condition gives the following labor demand expression for firm f:

$$L_{ft} = \frac{\beta^l R_{ft}}{W^l_{it}(1+\Psi^l\tilde{\lambda}_{it})}$$

Summing across firms, this implies the following market-level demand function:

$$L_{it} = \frac{\beta^l R_{it}}{W^l_{it}(1+\Psi^l\tilde{\lambda}_{it})}$$

Equating labor supply and demand, we get the following equilibrium expressions for wages and employment:

$$\begin{cases} W^l_{it} &= \Big(\dfrac{\beta^l R_{it}\nu_{it}^{\frac{1}{\Psi^l}}}{1+\Psi^l\tilde{\lambda}_{it}}\Big)^{\frac{\Psi^l}{1+\Psi^l}} \\ L_{it} &= \Big(\dfrac{\beta^l R_{it}}{(1+\Psi^l\tilde{\lambda}_{it})\nu_{it}}\Big)^{\frac{\Psi^l}{1+\Psi^l}} \end{cases}$$

In the counterfactual exercise, we set the conduct parameter to $\tilde{\lambda}_{it} = \frac{1}{N_{it}}$ in the

Cournot scenario, to $\tilde{\lambda}_{it} = 1$ in the fully collusive equilibrium, and to $\tilde{\lambda}_{it} = \frac{\bar{\lambda}_{it}}{N_{it}}$ in the 'stable collusion' counterfactual, in which $\bar{\lambda}_{it}$ is the value for the conduct parameter in every labor market as estimated right before the start of the cartel in 1897.

A.5.2 Model with endogenous prices

Next, we turn to the case with endogenous goods prices. We solve for joint labor and product market equilibrium subject to the production function (1), the labor supply curve (3), and the coal demand function (18). Assuming profit maximization and maintaining the assumption of symmetric firms within each labor market, we get the following firm-level labor demand curve:

$$L_{ft} = \frac{\beta^l Q_{ft} P_{it} \xi_{it}(1+\eta\tilde{\lambda}_{it})}{W^l_{it}(1+\Psi^l\tilde{\lambda}_{it})}$$

Aggregating to the market level gives the following market-level labor demand curve:

$$L_{it} = \frac{\beta^l Q_{it}^{1+\eta} \xi_{it}(1+\eta\tilde{\lambda}_{it})}{W^l_{it}(1+\Psi^l\tilde{\lambda}_{it})}$$

Equating labor demand and supply results in:

$$L_{it} = \Big(\frac{\beta^l Q_{it}^{1+\eta} \xi_{it}(1+\eta\tilde{\lambda}_{it})}{\nu_{it}(1+\Psi^l\tilde{\lambda}_{it})}\Big)^{\frac{1}{1+\Psi^l}}$$

Given that intermediate input prices W^m and capital prices W^k are assumed to be exogenous, material and capital demand is:

$$\begin{cases} M_{it} = \Big(\frac{\beta^m Q_{it}^{1+\eta} \xi_{it}(1+\eta\tilde{\lambda}_{it})}{W^m}\Big) \\ K_{it} = \Big(\frac{\beta^k Q_{it}^{1+\eta} \xi_{it}(1+\eta\tilde{\lambda}_{it})}{W^k}\Big) \end{cases}$$

Summing output to the market-level, $Q_{it} = \sum_{f\in i} Q_{ft}$, and substituting the input demand expressions into the production function gives the following equilibrium output expression:

$$Q_{it} = \Bigg(\Big(\frac{\beta^l \xi_{it}(1+\eta\tilde{\lambda}_{it})}{\nu_{it}(1+\Psi^l\tilde{\lambda}_{it})}\Big)^{\frac{\beta^l}{1+\Psi^l}} \Big(\frac{\beta^m \xi_{it}(1+\eta\tilde{\lambda}_{it})}{W^m}\Big)^{\beta^m} \Big(\frac{\beta^k \xi_{it}(1+\eta\tilde{\lambda}_{it})}{W^k}\Big)^{\beta^k}\Bigg)^{\frac{1}{1-\frac{(1+\eta)\beta^l}{1+\Psi^l}-(1+\eta)\beta^m-(1+\eta)\beta^k}}$$

Substituting this equilibrium output expression in the labor demand and coal demand functions, we obtain equilibrium employment, wages, and coal prices for each value of the conduct parameter $\tilde{\lambda}_{it}$.

B Data

B.1 *Administration des Mines* archives

B.1.1 Historical background

The institutional framework of Belgian coal mining was put in place by the French state, which governed the region from 1794 to 1814. By law of 28 July 1791, all mineral resources belonged to the state and could only be exploited under concession and surveillance of the state. Accordingly, the *Conseil des Mines* was founded: this government institute dispatched inspectors and mining engineers to all mining concessions on a yearly basis. While these visits were initially of a rather advisory nature, the role of the mine inspection would gradually be expanded towards an effective supervision unit in terms of "vices, dangers or abuses" by the end of the French period (Caulier-Mathy, 1971, 117).[I] The fall of the French empire and Belgium's annexation to the Netherlands would not have a major impact on the French mining legislation in place (Leboutte, 1991, 707).[II] In fact, the new Belgian government established the *Conseil des Mines de Belgique* by the law of 2 May 1837, which was to fill the institutional gap left behind by its French counterpart (Geerkens, Leboutte, & Péters, 2020, 293).

Due to its French roots, the close supervision of the mining industry presents us with a valuable exception to the *laissez-faire* principles of the Belgian state. Crucially, this translated into a vast body of statistical inquiries and visit reports. We leverage this archival information to construct a micro-level panel data set, covering all coal mining activities in Liège and Namur on a yearly basis. The oldest consistent data we could retrieve traces back to 1845, allowing us to build a comprehensive data set from 1845 to 1913. This endeavour was facilitated by the consistent nature of reporting by the engineers of the *Administration des Mines*, allowing for the straightforward inte-

[I] Important was the law of 21 April 1810, which imposed a set of requirements (*cahier de charges*) on mine exploitations to guarantee their competencies. Official engineers were tasked to verify and enforce these regulations under the banner of the *Administration des Mines*, established on 3 January 1813.

[II] From a governance perspective, some changes were implemented as most state engineers quit Belgium after the retreat of the imperial army in 1814. The French engineer Boüesnel would, however, stay and be appointed Chief Engineer under Dutch rule. He would subsequently also enter Belgian service, providing continuity and knowledge transfers to the mining department (Delrée & Linard de Guertechin, 1963, 54-55).

gration of the yearly accounts into a uniform data structure.[III] We refer to Figure B.3 for an illustration on what the original data looks like.

B.1.2 Construction of the variables

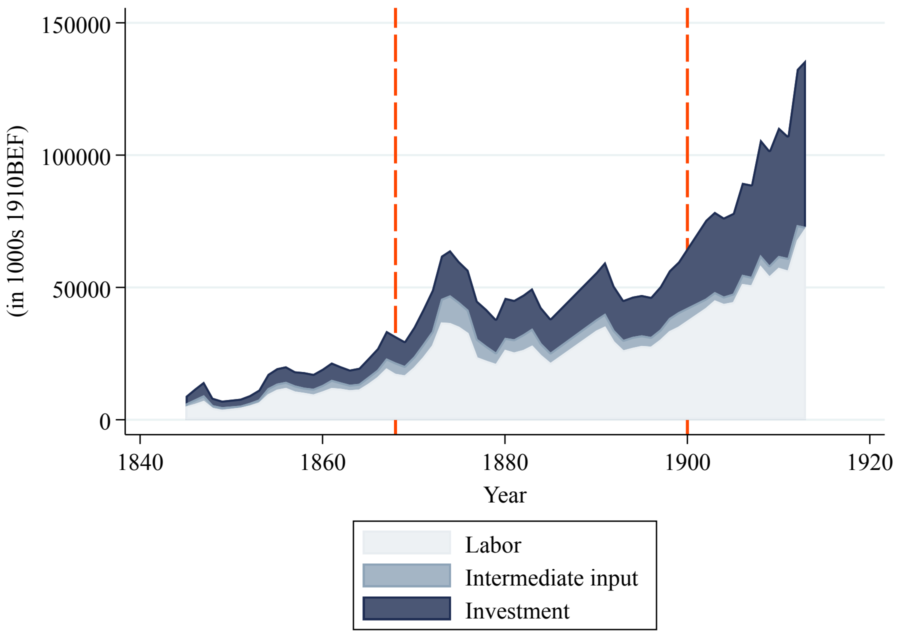
In this section, we provide a structural overview of how we constructed the variables for our empirical analysis. As outlined above, the data collected by the mining engineers are remarkably consistent over the almost-70-year period. In the case of the expenditure statistics, however, some changes in terminology were implemented throughout the years:

- Up to 1868:
  - Labor = Labor expenditure
  - Intermediate inputs = Other current expenditure
  - Investment = Preparatory investment (*Dépenses préparatoires*)
- 1869-1899:
  - Labor = Current labor expenditure
  - Intermediate inputs = Other current expenditure
  - Investment = Extraordinary expenditure (*Dépenses extraordinaires*)
- 1900-1913:
  - Labor = Current labor expenditure
  - Intermediate inputs = Other current expenditure
  - Investment = Extraordinary expenditure (*Dépenses extraordinaires*) + 'Expenses for first use' (*Dépenses premier ...*).

The class of extraordinary expenses, which changes in terminology throughout the years, includes all costs related to major expansion, transformation, and preparation work within the mines (Wibail, 1934, 13). Using these aggregations, we were able to create consistent measures of input expenditures and capital investments. In Figure B.1, we plot the cost shares according to our database. The dashed vertical lines indicate the years in which possible discontinuities in the variable definitions occur. The great continuity in the cost structure around these structural breaks alleviates any concerns regarding inconsistent definitions of the variables.

[III] This consistency was already exploited at the macro-level using the aggregated published statistics in Wibail (1934). The hand-written mine-level files, however, have been largely left untouched by historical research.

Figure B.1: **Structural composition of the expenses, 1845-1913**



Notes: This figure plots total expenditure on labor, intermediate inputs, and capital investment in the dataset. The dashed vertical lines represent the changes in terminology of the variables.

For a small subset of years, wages are distinguished into gross and net wages, with the difference being due to participation in insurance schemes. In these cases, we opted to use the net wages in our analysis. For some years, especially the earlier and later periods, employment counts are disaggregated by worker age and gender, but we only use the aggregate employment counts across ages and gender.

Finally, we note that the historical sources assign the concessions to communities on a yearly basis. As a general rule, we follow the descriptions in the original data sheets, which we use to link the mines to contextual data from other sources (see Appendix B.2).

B.1.3 Concession and firm composition

As outlined in Section B.2, Belgium's coal mining sector was organized around concessions in which firms conditionally received mining rights to the state's mineral resources. The general regulation was thus generally organized according to these concessions. Such concessions were typically independent and separate production units with their own respective *directeurs des travaux* (managers). In the main analysis, we consequently considered these concessions to be independent firms.

Nevertheless, it is important to emphasize that this assumption potentially discards certain firm dynamics regarding the acquisition and merger of mining concessions. Firms were legally allowed to own multiple concessions,[IV] and this implies that our findings of monopsony and employer collusion are potentially biased upwards by within-firm coordination. We argue, however, that this is not a likely driver behind our conclusions on the ubiquity of employer collusion. For the period 1896-1913, we do have access to comprehensive accounts of active mining concessions and their respective *sociétés exploitantes* (exploiting firms) in the form of the *Tableaux des mines de houille en activité* (Administration des Mines, 1896–1913). Table B.1 reveals that, for the *bassins* of Liège and Namur, all but one firm exploited a single concession in 1896. By 1913 (see Table B.2), there were still only two exceptions to this rule.[V] This confirms that our empirical evidence on employer collusion for this period is not driven merely by labor market coordination across concessions within single firms.

Going back in time, however, our view on the firm-concession relationship becomes somewhat more obscure. Fortunately, we were able to reconstruct the histories of most Liège- and Namur-based *Sociétés Anonymes* (or S.A., an equivalent to public companies). This type of enterprise was very popular among the biggest coal companies as it facilitated funds acquisition in the capital-intensive business of mining. In other words, the biggest holdings - which are arguably the most likely to have exploited multiple concessions - are covered by our manually collected database of 19$^{\text{th}}$-century

[IV] Article 31 in the law of 21 April 1810 reads:

> *Several concessions may be brought together in the hands of the same concessionaire, either as an individual or as a representative of a company, but at the expense of maintaining the operation of each concession.*

[V] Multiple-concession firms appear to have been located primarily in the *Bassin du Couchant de Mons*, not surprisingly the area in which universal banks had the strongest hold on the coal industry: we return to this issue of inter-firm ownership below.

public coal companies.

In general, it appears that firms preferred to unite concessions under their supervision as "their reunion and a single concession can only be advantageous to the good development and economic exploitation of the mine".[VI] Specific reasons include the removal of fences (for example, see Demeur, 1878, 672), the ability to mine veins under concession borders (for example, see Recueil Financier, 1893, 159), as well as administrative simplicity in terms of government supervision. As a consequence, most firm mergers or acquisitions were followed by the unification of the firms' concessions as well.[VII]

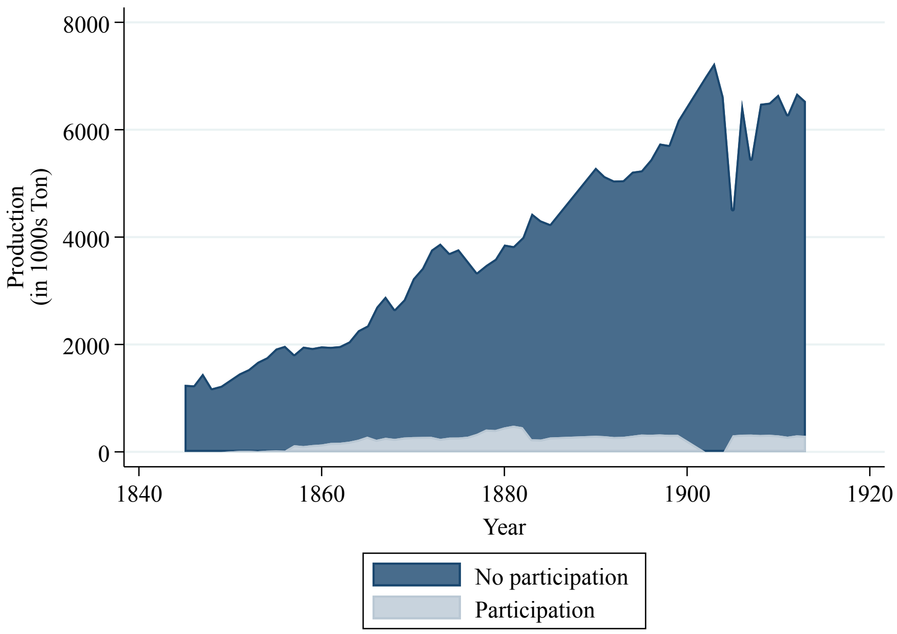
A more prevalent connection between the concessions in our database appeared to have in been the form of *common* and, more importantly, *inter-firm ownership*. Collusion due to *common ownership* is probable if powerful investment banks had a strong hand in multiple exploitations. As discussed in Section 2.3, Hainaut-based coal firms with their mutual ties to the *Société Générale de Belgique* were indeed openly colluding in wage setting. In the case of Liège- and Namur-based coal mining, however, this appears to have been less clear. Our analysis of the portfolio of the *Société Générale*, by far the most powerful and omnipresent universal bank in 19th-century Belgium (Van Overfelt, Annaert, De Ceuster, & Deloof, 2009), reveals that its involvement in coal mining was strongly confined to the *bassins* in Hainaut.[VIII] In Figure B.2, we decompose coal production in Liège and Namur by whether a firm had some financial ties (in the form of stock ownership) with the *Société Générale.* This illustrates that the universal bank's control over this industry was limited and that its development over time does little to explain the observed monopsony and employer collusion surge after the turn of the century. This conclusion aligns with historical appraisals of the industrial relations in Liège during that era (Kurgan-van Hentenryk & Puissant, 1990).

[VI]This is a translated quote from the royal decree regarding the unification of the concessions from the *SA des charbonnages de la Chartreuse et Violette* (Demeur, 1878, 680-681).

[VII]For examples, see the aforementioned case of *SA des charbonnages de la Chartreuse et Violette*, as well as the case of *SA des charbonnages de Bonne-Fin*, which fully acquired the concession of Baneux in August 1863. Early in the year following this acquisition, the concessions of Bonne-Fin and Baneux were united (Laureyssens, 1975, 139).

[VIII]We thank Gertjan Verdickt and the *StudieCentrum voor Onderneming en Beurs* or SCOB (University of Antwerp) for help with this data.

Figure B.2: **Involvement of the *Société Générale de Belgique* in Liège- and Namur-based coal mining, 1845-1913**

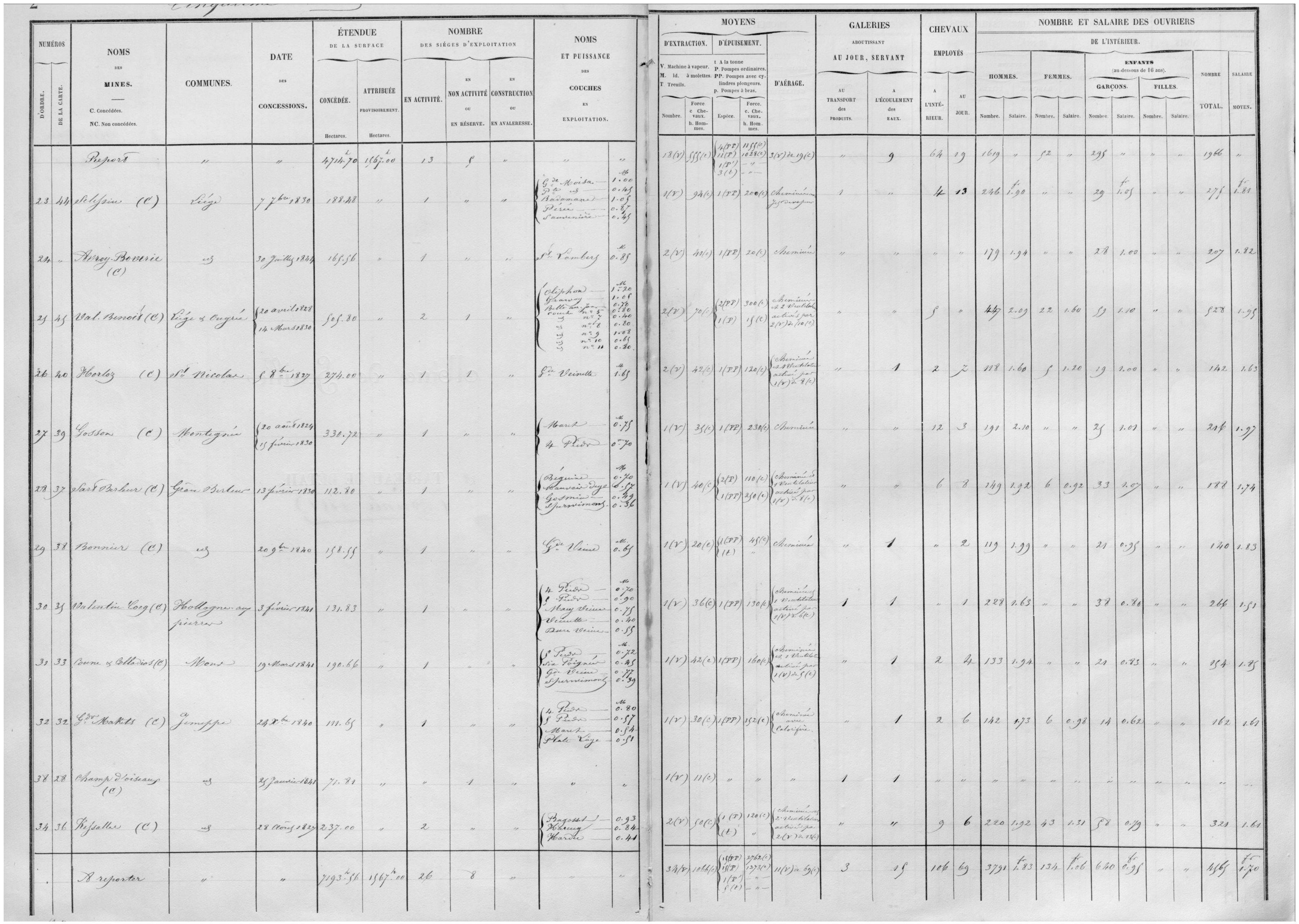


Notes: This graph shows total output produced by coal firms in which the *Société Générale* participated, and by all other coal firms.
Source: Authors' database and the yearbooks of the *Société Générale de Belgique* (SCOB).

Inter-firm ownership, on the other hand, implies that industrial conglomerates had a hand in multiple, competing concessions other than their own exploitation, pressuring its managers into aligning their labor market strategies. We see this as a plausible source of employer-side collusion in industrial labor markets. A prime example is undoubtedly the influential Liège-based Orban family. Jean-Michel Orban (1752-1833) was among the first to successfully implement innovations in mechanized water pumping and animal-powered coal transport. Hence, other firms asked him to participate in their coal mining ventures, expanding his involvement in the local coal industry. His son Henri-Joseph Orban (1779-1846) and other relatives would continue to tighten the family's grip on the local industry (Kurgan-Van Hentenryk, Puissant, & Montens, 1996, 491). At Henri-Joseph Orban's death in 1846, his inheritance listed financial ties with various firms in our sample, including the *Houillère de Nouvelle Bonnefin*, the *Houillère des Baneux* and the *Houillère du Bon Buveur* (Capitaine, 1858, 13). Comprehensively charting such financial ties over time for the Orban family, as well as for other industrial dynasties such as the Cockerill family, is beyond the scope of this paper (if not beyond the scope of the available historical sources as well).

Nevertheless, we do see the connection between inter-firm ownership and labor market collusion as an exciting avenue for future research.

Figure B.3: **Example of one of the count sheets of the *Administration des Mines***



Source: Administration des Mines (1831–1933, Series 103).

Table B.1: **Concession and firm concordance in Liège and Namur, 1896**

Basin & District		**Concession**	**Firm**
Bassin de Namur	5	Hazard	SC du charbonnage du Hazard
	5	Auvelais Saint-Roch	SA des charbonnages de Saint-Roch-Auvelais
	5	Falisolle	SA du charbonnage de Falisolle
	5	Arsimont	SA du charbonnage d'Arsimont
	5	Ham-sur-Sambre	SA des charbonnages de Ham-sur-Sambre et Moustier
	5	Malonne	SA des charbonnages de Malonne et Floreffe
	5	Le Château	SC du charbonnage de Château
	5	Basse-Marlagne	SC du charbonnage de Basse-Marlagne
	5	Stud-Rouvroy	SC du charbonnage de Stud-Rouvroy
	5	Andenelle	SC du charbonnage d'Andenelle
	5	Groynne	SC du charbonnage de Groynne
Bassin de Liège	6	Bonnier	SA du charbonnage du Bonnier
	6	Sarts-au-Berleur	SA du charbonnage du Corbeau-au-Berleur
	6	Gosson-Lagasse	SA des charbonnages de Gosson Lagasse
	6	Horloz	SA des charbonnages du Horloz
	6	Kessales-Artistes	SA des charbonnages des Kessales
	6	Concorde	SA des charbonnages réunis de la Concorde
	6	Nouvelle-Montagne	SA de Nouvelle-Montagne
	6	Halbosart	Famille Farcy
	6	Ben	Desoer et Compagnie
	6	Marihaye	SA des charbonnages de Marihaye
	6	Bois de Gives et Saint-Paul	SC des charbonnages de Gives et Saint-Paul
	7	Angleur	SA des charbonnages d'Angleur
	7	Sclessin-Val Benoit	SA des charbonnages du Bois d'Avroy
	7	Espérance et Bonne Fortune	SA des charbonnages d'Espérance et Bonne Fortune
	7	La Haye	SA des charbonnages de La Haye
	7	Patience-Beaujonc	SA des charbonnages de Patience-Beaujonc
	7	Bonne-Fin Bâneux	SA des charbonnages de Bonne-Fin
	7	Ans et Glain	SA des Mines de houile d'Ans
	7	Grande-Bacnure	SA de la Grande Bacnure
	7	Petite-Bacnure	SA des charbonnages de la Petite Bacnure
	7	Belle-Vue et Bien Venue	SA des charbonnages de Belle-Vue et Bien-Venue
	7	Espérance (Herstal)	SA de Bonne-Espérance et Batterie
	7	Batterie	SA de Bonne-Espérance et Batterie
	7	Abhooz et Bonne-Foi-Hareng	SA des charbonnages d'Abhooz et Bonne-Foi-Hareng
	7	Bicquet-Gorée	SA des charbonnages d'Oupeye
	8	Cockerill	SA John Cockerill
	8	Cowette-Rufin	SC de Cowette-Rufin, Grand-Henri
	8	Crahay	SA de Maireux et Bas-Bois
	8	Hasard-Melin	SA du Hasard
	8	Herman-Pixherotte	SC de Herman-Pixherotte
	8	Herve-Wergifosse	SA de Herve-Wergifosse
	8	Lonette	SA de Lonette
	8	Micheroux	SA dus Bois de Micheroux
	8	Minerie	SA de la Minerie
	8	Ougrée	SA d'Ougrée
	8	Près de Fléron	SC des Près de Fléron
	8	Quatre Jean	SA des Quatre Jean
	8	Six-Bonniers	Société charbonnière des Six-Bonniers
	8	Steppes	SC du canal de Fond-Piquette
	8	Trou-Souris-Houlleux-Homvent	Charbonnages réunis de l'Est de Liège
	8	Wandre	Suermondt, frères
	8	Wérister	SA de Wérister

Notes: *Sociétés Anonymes* and *Sociétés Civiles* are abbreviated as SA and SC respectively. Firms underlined and in blue are multiple-concession firms.

Source: Annales des Mines de Belgique (1896–1913, vol. I).

Table B.2: **Concession and firm concordance in Liège and Namur, 1913**

Basin & District		**Concession**	**Firm**
Bassin de Namur	5	Tamines	SA des charbonnages de Tamines
	5	Auvelais Saint-Roch	SA des charbonnages de Saint-Roch-Auvelais
	5	Falisolle	SA du charbonnage de Falisolle
	5	Ham-sur-Sambre, Arsimont et Mornimont, Franière et Diminche	SA des charbonnages de Ham-sur-Sambre et Moustier
	5	Jemeppe-sur-Sambre	SA du charbonnage de Jemeppe-Auvelais
	5	Soye, Floriffoux, Floreffe, Flawinne, La Lâche et extensions	SA des charbonnages réunis de la Basse Sambre
	5	Le Château	SC du charbonnage de Château
	5	Basse-Marlagne	SC du charbonnage de Basse-Marlagne
	5	Stud-Rouvroy	SC du charbonnage de Stud-Rouvroy
	5	Groynne	SC du charbonnage de Groynne
	5	Andenelle, Hautebise et Les Liégeois	SC du charbonnage de Hautebise
	5	Muache	Victor Massart
Bassin de Liège	6	Bois de Gives et Saint-Paul	SC des charbonnages de Gives et Saint-Paul
	6	Halbosart-Kivelterie	SA des charbonnages de Halbosart
	6	Sart d'Avette et Bois des Moines	SA des charbonnages du Pays de Liège
	6	Arbre Saint-Michel, Bois d'Otheit et Cowa	SA des charbonnages de l'Arbre Saint-Michel
	6	Nouvelle-Montagne	SA de Nouvelle-Montagne
	6	Marihaye	SA d'Ougrée-Marihaye: Division Marihaye
	6	Kessales-Artistes	SA des charbonnages des Kessales
	6	Concorde	SA des charbonnages réunis de la Concorde
	6	Sarts-au-Berleur	SA du charbonnage du Corbeau-au-Berleur
	6	Bonnier	SA du charbonnage du Bonnier
	6	Gosson-Lagasse	SA des charbonnages de Gosson Lagasse
	6	Horloz	SA des charbonnages du Horloz
	7	Espérance et Bonne Fortune	SA des charbonnages d'Espérance et Bonne Fortune
	7	Ans et Glain	SA des Mines de houile d'Ans et de Rocour
	7	Patience-Beaujonc	SA des charbonnages de Patience-Beaujonc
	7	La Haye	SA des charbonnages de La Haye
	7	Sclessin-Val Benoit	SA des charbonnages du Bois d'Avroy
	7	Bonne-Fin Bâneux	SA des charbonnages de Bonne-Fin
	7	Batterie	SA de Bonne-Espérance et Batterie
	7	Espérance et Violette	SA de Bonne-Espérance et Batterie
	7	Abhooz et Bonne-Foi-Hareng	SA des charbonnages d'Abhooz et Bonne-Foi-Hareng
	7	Petite-Bacnure	SA des charbonnages de la Petite Bacnure
	7	Grande-Bacnure	SA de la Grande Bacnure
	7	Belle-Vue et Bien Venue	SA des charbonnages de Belle-Vue et Bien-Venue
	7	Bicquet-Gorée	SA des charbonnages d'Oupeye
	8	Cockerill	SA John Cockerill
	8	Six-Bonniers	Société charbonnière des Six-Bonniers
	8	Ougrée	SA d'Ougrée-Marihaye
	8	Trou-Souris-Houlleux-Homvent	Charbonnages réunis de l'Est de Liège
	8	Steppes	SC du canal de Fond-Piquette
	8	Cowette-Rufin	SC de Cowette-Rufin, Grand-Henri
	8	Wérister	SA des charbonnages de Wérister
	8	Quatre Jean	SA des Quatre Jean
	8	Lonette	SA de Lonette
	8	Hasard-Fléron	SA des charbonnages de Hasard
	8	Crahay	SA des charbonnages de Maireux et Bas-Bois
	8	Micheroux	SA du charbonnage de Bois de Micheroux
	8	Herve-Wergifosse	SA de Herve-Wergifosse
	8	Minerie	SA des charbonnages réunis de la Minerie
	8	Wandre	Suermondt, frères
	8	Cheratte	SA des charbonnages de Cheratte
	8	Basse-Ransy	SA des charbonnages de la Basse-Ransy

Notes: *Sociétés Anonymes* and *Sociétés Civiles* are abbreviated as SA and SC respectively. Firms underlined and in blue are multiple-concession firms.

Source: Annales des Mines de Belgique (1896–1913, vol. XVIII).

B.2 Other sources

B.2.1 Membership of the *Union des charbonnages*

To quantify membership of the *Union des charbonnages, mines et usines métallurgiques de la province de Liège* throughout the years, we constructed a yearly binary membership variable for each firm in our data set. In their monthly *Bulletin* publications (1869–1913), the organization disseminated the minutes of its meetings, as well as noteworthy news in the local coal industry. On a yearly basis, a complete list of its members was also published. We used the latter as a source for our membership variable.

This variable does not cover the period before the *Union* was officially registered, from 1840 to 1868. Based on the available member lists, there is no evidence of exit from the union, so we assume that all members who remained members from 1868 to 1913 were founding members and, accordingly, create a time invariant membership dummy.

B.2.2 Employers' associations in Namur

Most *bassins* in Belgium had their own respective employers' organizations, much like the *Union*. However, the smaller and more dispersed Namur coal industry - the other *bassin* in our data set next to Liège, Basse-Sambre - was an exception. The Charleroi-based *Association des charbonnages du bassin de Charleroi* did attempt to gain control over this area. In order to attract more Namur-based coal mines, the organization changed their name into *L'Association charbonnière et l'industrie houillière des bassins de Charleroi et de la Basse-Sambre* (?, ?, 30). Membership lists of said organization reveal that the reach of these efforts was very limited in terms of membership, however.

B.2.3 Access to the railroad network

We assigned the coal mines' location to their respective communities. The transport database of the *Quetelet Center for Quantitative Historical Research* (Ghent University) gives us access to the opening years of all train and tramway stations in Belgium. By combining these two sources of information, we were able to retrace all coal mines' approximate year of connection to the Belgian railroad network.

B.2.4 Cartel membership

The work of contemporary economist Georges De Leener is without a doubt considered to be the seminal source on Belgian cartels of that era (for example, see Vanthemsche, 1995, 18). We obtain the cartel membership list in 1905 from De Leener (1909). We trace this cartel membership data back to 1898 by taking into account name changes of mines and assume that no firms entered or exited the cartel between 1898-1905. This results in 27 cartel firms in 1898, which is in line with anecdotal evidence in De Leener (1904). After 1905, we take into account the exit of the *Gosson-Lagasse* mine in 1907, as mentioned by De Leener (1909), and for the remainder, we assume that the cartel membership remained stable, as no mention of any other exiters or entrants was made in De Leener (1909).

B.3 Constructing the capital stock

In this section, we describe how we construct the capital stock K_{ft}. In every year between 1846 and 1912, we observe capital investment I_{ft} from the variable *dépenses extraordinaires*. We specify the usual capital accumulation equation:

$$K_{ft} = K_{ft-1}(1 - \delta) + I_{ft}$$

In order to determine the amount of of depreciation, we estimate the capital transition process for both machine horsepower and equine horsepower. The estimates are in Table B.3. If no investment has taken place in the previous year, machine horsepower decreases by 12.7% and equine horsepower by 15.1%. If there has been investment in the previous year, machine horsepower increases by 1.7%, but equine horsepower remains stable: investments in horses were mainly replacement investments, not expanding the amount of horses used. Given that the depreciation rates lay around 13%, we set $d = 0.13$ in order to calculate the capital stock. For years in which investment data are missing, we linearly interpolate missing investments.

Table B.3: **Estimates of depreciation (firm-year-level)**

Panel A: Machine horsepower	Not invested		Invested	
	Est.	S.E.	Est.	S.E.
$1 - \delta$	0.873	0.061	1.017	0.005
R-squared	.782		.974	
Observations	3558		3279	
Panel B: Equine horsepower	Not invested		Invested	
	Est.	S.E.	Est.	S.E.
$1 - \delta$	0.849	0.073	0.993	0.012
R-squared	.721		.934	
Observations	3558		3279	

Notes: We estimate depreciation by regressing horsepower on lagged horsepower for both machines and horses, both if firms invested in the previous period and if they did not invest. Robust standard errors are included.

One problem is which capital stock to assume in the first year of the data set, 1845. This was most likely not zero. We proceed as follows to find the initial capital stock. We regress yearly investment on changes in the number of horsepower for excavation and extraction, K^1 and K^2, and the change in the number of horses K^h in order to recover the price per horse and the price per unit of horsepower for each machine.

$$I_{ft} = W^1(K^1_{ft} - K^1_{ft-1}) + W^2(K^2_{ft} - K^2_{ft-1}) + W^h(K^h_{ft} - K^h_{ft-1}) + u_{ft}$$

The estimates for W^1, W^2, and W^h are in Table B.4. Next, using these capital price estimates, we compute the initial capital stock in 1845 as:

$$K_{f,1845} = W^1 K^1_{f,1845} + W^2 K^2_{f,1845} + W^h K^h_{f,1845}$$

We assume the deflated prices per horse and horsepower to be constant across firms and years. This assumption could be violated if machine technologies became cheaper over time. However, we only need the price per horsepower and horse in 1845 to construct the initial capital stock, not the price per horsepower and horse in every year.

Table B.4: **Recovering capital prices (firm-year-level)**

	Capital investment	
	Est.	S.E.
Δ H.P. of water extraction machines	371.757	103.328
Δ H.P. of hauling machines	153.167	49.360
Δ No. of horses	2397.790	955.255
R-squared	.059	
Observations	8013	

Notes: We regress annual capital investment per firm on the change in water extraction machinery and hauling machines, measured in horsepower, and the change in the number of horses. Robust standard errors are included.

B.4 Summary statistics

Table B.5: **Summary statistics of concession/firm characteristics**

	Min.	p10	p25	Mean	p75	p90	Max.
Total active concessions	40.00	52.000	56.000	78.304	99.000	104.000	112.00
Total concessions	115.00	120.000	123.000	143.606	157.000	161.000	164.00
Duration of concession in data (years)	1.00	25.000	41.000	50.289	62.000	62.000	62.00
Exit share of firms	0.00	0.016	0.030	0.049	0.061	0.082	0.20
Exit share of employment	0.00	0.000	0.001	0.022	0.028	0.073	0.11
Total output (tonnage)	3.00	1137.000	4016.000	53175.178	64052.500	150587.000	540650.00
Cost share: Labor	0.00	0.426	0.528	0.579	0.649	0.715	1.00
Cost share: Materials	0.00	0.191	0.260	0.318	0.370	0.425	1.00
Cost share: Capital	0.00	0.026	0.048	0.133	0.163	0.304	1.00

Notes: The cost share statistics are conditional on the cost shares being non-zero. However, the minimum cost shares are very small and rounded to zero in the table.

B.5 Sample sizes

Table B.6 shows the sample sizes in the different empirical specifications and the reasons for the differences in sample sizes.

Table B.6: **Sample sizes**

Panel A: Firm-level:	N	Table
(i) All	8779	
(ii) Observe $q_{ft}, l_{ft}, m_{ft}, k_{ft}, w_t^{agri}$	4480	1(a) left column
(iii) Observe (ii) and its first lag	4005	1(a) right column
(iv) Observe $\ln(\mu^l_{ft})$	4705	2(a) right column
(v) Observe $\ln(\mu^l_{ft})$ and cartel/union membership	4432	2(a) left column
(vi) Observe (v) prior to 1898	3737	2(b) left column
(vii) Observe (v) after to 1898	695	2(b) right column
(viii) Observe s_{ft}, $\ln(\mu^l_{ft})$	4671	3(a)
(ix) Observe s_{ft}, $\ln(\mu^l_{ft})$ and cartel membership for non-cartel firms	3183	3(b)
(x) Observe s_{ft}, $\ln(\mu^l_{ft})$ and cartel membership for cartel firms	1472	3(c)
Panel B: Market-level:	N	Table
(i) All	2624	
(ii) Observe l_{ft}, w^l_{ft} + instruments	1990	1(c)

C Robustness checks

In this section, we present a range of robustness checks and alternative specifications to the model in the main text. We organize these as following:

		Section
Production function:	Non-constant output elasticities	C.1.1
	Imposing a returns to scale parameter	C.1.2
	Translog production function	C.1.3
	Time-varying production function	C.1.4
	Input and product differentiation	C.1.5
	Intermediate input market power	C.1.6
	First differences	C.1.7
	Cost shares approach	C.1.8
	Serial correlation in estimated productivity shocks	C.1.9
	Extension to multi-product firms	C.1.10
	Cost dynamics	C.1.11
	Production coefficients with different IV selections	C.1.12
Labor supply:	Wage variation and firm fixed effects	C.2.1
	Test for employer differentiation	C.2.2
	Differentiated employers models	C.2.3
	Time-varying labor supply elasticity	C.2.4
	Labor market definitions	C.2.5
	Different definition of the labor demand shock	C.2.6
	Different instrument selection	C.2.7
Other:	Compensating differentials	C.3.1
	Aggregation	C.3.2
	Political changes and democratization	C.3.3

C.1 Production function: extensions and robustness

C.1.1 Non-constant output elasticities

In the main text, we relied on a Cobb-Douglas production function, which implies constant output elasticities of labor and materials, β^l and β^m. In this appendix, we consider various production models with heterogeneous output elasticities. We define the output elasticities of labor and materials as $\theta^l_{ft} \equiv \frac{\partial Q_{ft}}{\partial L_{ft}} \frac{L_{ft}}{Q_{ft}}$ and $\theta^m_{ft} \equiv \frac{\partial Q_{ft}}{\partial M_{ft}} \frac{M_{ft}}{Q_{ft}}$.

The markup expressions from the main text generalize to:

$$\mu_{ft} = \frac{\theta^l_{ft}}{\alpha^l_{ft}(1 + \tilde{\lambda}_{ft}\Psi^l)}$$

$$\mu_{ft} = \frac{\theta^m_{ft}}{\alpha^m_{ft}}$$

Similarly, the markdown equation becomes:

$$\frac{1}{1 + \tilde{\lambda}_{ft}\Psi^l} = \frac{\theta^l_{ft} W^m_{ft} M_{ft}}{\theta^m_{ft} W^l_{ft} L_{ft}}$$

C.1.2 Imposing a returns to scale parameter

We re-estimate the Cobb-Douglas production model from the main text, but now calibrate the returns to scale parameter $\varsigma \equiv \beta^l + \beta^m + \beta^k$ at a known value, rather than estimating it. This allows estimating the model with more precision, but comes at the cost of imposing an assumption on the degree of returns to scale. We alternatively impose constant returns to scale, $\varsigma = 1$, and two different values of increasing returns to scale, $\varsigma = 1.05$ and $\varsigma = 1.1$. The production function in logs that needs to be estimated becomes Equation C.1.

$$q_{ft} = \beta^l l_{ft} + \beta^m m_{ft} + (\varsigma - \beta^m - \beta^l) k_{ft} + \omega_{ft} \tag{C.1}$$

We follow the same estimation strategy in the main text, which results in the moment conditions in Equation (C.2). We now need to estimate one parameter less than in the main text.

$$\mathbb{E}\Big[q_{ft}-\rho q_{ft-1}-\beta^0(1-\rho)-\beta^l(l_{ft}-\rho l_{ft-1})-\beta^m(m_{ft}-\rho m_{ft-1})-\varsigma-\beta^l-\beta^m(k_{ft}-\rho k_{ft-1}) \\ |(l_{ft-1},m_{ft-1},k_{ft},k_{ft-1},w^{agri}_{t-1})\Big]=0 \quad \text{(C.2)}$$

Table C.1 shows the resulting production function and markdown/markup estimates. The first column imposes constant returns to scale, $\varsigma = 1$, the second and third columns allow for increasing returns to scale, $\varsigma = 1.05$ and $\varsigma = 1.1$. In all three versions, the coefficients are estimated much more precisely than in the main text. Imposing constant returns to scale leads to a negative capital elasticity and to a wage markdown below one, meaning that workers are paid more than their marginal revenue product, both of which seem highly unlikely. However, our main model (noisily) estimated returns to scale to be increasing, at 1.07. If we calibrate returns to scale to be increasing at either 1.05 or 1.10, we find output elasticities and markdown/markup estimates that are much in line with the main model, but more precisely estimated. In Figure C.1, we plot the evolution of the corresponding collusion index for the three specifications. In both specifications with increasing returns to scale, we find that the collusion parameter lies on average above the Cournot lower bound and increases sharply after the cartel's introduction. Imposing $\varsigma = 1.05$ leads to an increase of the markdown to the fully collusive markdown bound after 1897, under $\varsigma = 1.1$ it increases to around 1.5 times the fully collusive markdown bound.

C.1.3 Translog production function

In order to allow for more flexibility in the production function, we estimate a translog production function, which allows for both interaction terms between all inputs and nonlinearities in the output elasticities. We rely on the same moment conditions as in the main text to estimate this equation, but we add the transformations of the instruments as additional instrumental variables.

$$q_{ft}=\beta^l l_{ft}+\beta^m m_{ft}+\beta^k k_{ft}+\beta^{kl}k_{ft}l_{ft}+\beta^{km}k_{ft}m_{ft}+\beta^{lm}l_{ft}m_{ft}+\beta^{ll}l_{ft}^2+\beta^{kk}k_{ft}^2+\beta^{mm}m_{ft}^2+\omega_{ft} \quad \text{(C.3)}$$

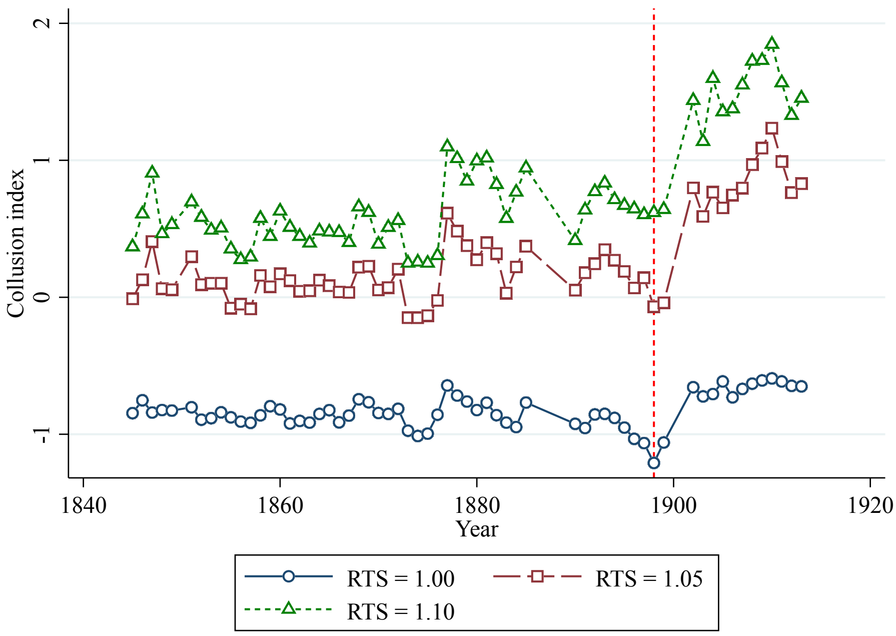
We estimate this equation in Table C.11. The resulting employer collusion series

Table C.1: **Imposing a returns to scale parameter: production estimates**

	$\varsigma = 1$		$\varsigma = 1.05$		$\varsigma = 1.1$	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
Labor	0.550	0.031	0.661	0.041	0.731	0.046
Materials	0.460	0.040	0.237	0.080	0.214	0.044
Capital	-0.009	0.036	0.102	0.088	0.055	0.032
Wage markdown	0.687	0.114	1.598	0.457	1.959	0.720
Price markup	1.602	0.185	0.827	0.276	0.746	0.167
Hansen J-test	1.35		2.72		2.67	
Hansen J-test p-value	.507		.255		.262	
Observations	4005		4005		4005	

Notes: This table shows the production function estimates when imposing a returns to scale parameter $\varsigma \equiv \beta^l + \beta^m + \beta^k$. The first column imposes constant returns to scale, $\varsigma = 1$, the second and third columns allow for increasing returns to scale, $\varsigma = 1.05$ and $\varsigma = 1.1$. Block-bootstrapped standard errors are computed with 200 iterations.

Figure C.1: **Collusion estimates under imposing a returns to scale parameters**



Notes: This graph shows the evolution of the median of our collusion measure, $\hat{\lambda}$, when imposing a returns to scale parameter $\varsigma \equiv \beta^l + \beta^m + \beta^k$: (i) constant returns to scale ($\varsigma = 1$) (ii) increasing returns to scale ($\varsigma = 1.05$) (iii) increasing returns to scale ($\varsigma = 1.1$)

is plotted as red squares in Figure C.3. Collusion is now estimated to fall in between 1845 and 1897, but it still increases substantially after the introduction of the cartel in

1897. Given that none of the interaction terms in the translog production function are statistically significant, we keep the Cobb-Douglas function as our main specification.

Table C.2: **Translog production model: coefficients, markups and markdowns**

Panel A: Production coefficients	Est.	S.E.
log(Labor)	1.303	1.582
log(Materials)	0.030	1.173
log(Capital)	0.279	0.421
log(Labor)*log(Capital)	-0.103	0.087
log(Labor)*log(Materials)	0.044	0.252
log(Materials)*log(Capital)	0.018	0.062
log(Labor)*log(Labor)	0.002	0.176
log(Materials)*log(Materials)	-0.023	0.084
log(Capital)*log(Capital)	0.036	0.021
Panel B: Markups/markdowns	Est.	S.E.
Average markdown	2.178	11.978
Average markup	0.709	0.765

Notes: Panel A reports the estimates of the translog production function. Panel B reports the corresponding average markdown and markup. Block-bootstrapped standard errors are computed with 200 iterations.

C.1.4 Time-varying production function

In the main text, the production function coefficients were assumed to remain invariant over time. In this section, we extend the model to allow for time variation in these coefficients. As a first robustness check, we split the panel in two equally-sized periods (1845-1879 and 1880-1913) and estimate the model separately for these two periods. As a second check, we interact log labor with a linear time trend in the production function and, hence, allow the labor coefficient to change over time:

$$q_{ft} = \beta^l l_{ft} + \beta^m m_{ft} + \beta^k k_{ft} + \beta^l l_{ft} t + \beta^t t + \omega_{ft}$$

Third, we allow for a linear time trend in the productivity process, which implies adding a linear time trend to the production function.

The median collusion estimates obtained when allowing for time-varying production coefficients are plotted in Figure C.3. The model with two time blocks is indicated by the green triangles. We find a median collusion index around zero prior to the cartel and an increase to around 0.5 after the cartel. The production function estimates when splitting the sample are unrealistically high for the first period, and unrealistically low for the second period. However, they are estimated imprecisely and are not significantly different from each other. Given the limited power to estimate the baseline model on the entire sample period with constant coefficients over time, re-estimating the production model on a much smaller sample delivers very imprecise point estimates of the output elasticities. Hence, we prefer to stick to the baseline model which is estimated on the entire time period.

The model with a linear time trend in the output elasticity of labor, which is indicated by the purple diamonds, finds a large increase in employer collusion after the introduction of the coal cartel. We now find a collusion index around one prior to the cartel and an increase to a collusion index of 2 after the cartel. This implies that markdowns were twice the fully collusive upper bound, which is not supported by theory. Finally, the model in which a linear time trend in productivity is included, which is plotted as black crosses, delivers higher collusion estimates than our main specification, but contains a similar increase in collusion after the introduction of the cartel.

Panel A of Table C.3 shows the corresponding production function estimates. In the split-panel specifications, the output elasticities of all inputs fall over time, although they are not significant between both time periods for any coefficient. The interaction term of the labor elasticity with a linear time trend yields a coefficient that is very close to, and not significantly different from, zero. As we cannot reject constant output elasticities over time, we keep the time-invariant production model as our main specification.

Table C.3: **Time-varying production model: coefficients**

Panel A: Two time blocks	Labor		Materials		Capital	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
1845-1879:	1.571	0.315	0.643	0.199	0.220	0.076
1880-1913:	0.326	0.531	0.143	0.145	0.101	0.051
Panel B: time trend in labor coefficient	Labor		Labor*Year		Year	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
Coefficient:	2.379	16.010	-0.001	0.009	0.012	0.152
Panel C: time trend in productivity	Labor		Labor*Year		Year	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
Coefficient:	2.379	16.010	-0.001	0.009	0.012	0.152

Notes: Panel A estimates the production function with time block-specific coefficients, for two time blocks. Panel B includes a linear time trend in the output elasticity of labor. Panel C includes a linear time trend in the productivity residual. Block-bootstrapped standard errors are computed with 200 iterations.

C.1.5 Input and product differentiation

In the main text, we relied on the assumption that coal is a homogeneous product. In this section, we examine extensions of the model in which we allow for coal differentiation. First, if inputs and output are vertically differentiated and if higher quality inputs result in higher quality outputs, this causes biased production function coefficients as long as intermediate input prices are not controlled for in the production function (De Loecker et al., 2016). In the context of our paper, we think this concern does not apply because coal is differentiated only to a limited extent, and this differentiation is merely a result of geological conditions, not of input usage. Nevertheless, we address the possible 'input price bias' in two ways. First, we follow De Loecker et al. (2016) by adding a control function in output prices to the production function. We add a linear function of log prices as an input to the production function, and current and lagged log prices to the instruments vector. The resulting output elasticity estimates in the first column of Table C.4 are very similar to those in the main specification. Second, we measure coal quality as the share of high-quality anthracite coal (*houille maigre*) produced by the firm as this was the coal type with the highest caloric content. We add this quality measure as an additional input to the production function and add its current and lagged value to the instrumental variables vector. The estimates from this specification, which are in the first column of Table C.4, are also similar to those in the main specification. The median collusion estimates from the price control approach and the quality control approach are plotted as the red square and purple diamonds in Figure C.4 and are, again, very similar to those in the main text.

Table C.4: **Production models with product differentiation: coefficients and markups**

Panel A: Output elasticities	log(Output)		log(Output)	
	Est.	S.E.	Est.	S.E.
log(Labor)	0.750	0.222	0.702	0.324
log(Materials)	0.252	0.127	0.226	0.130
log(Capital)	0.148	0.047	0.154	0.071
Serial correlation	0.933	0.111	0.870	0.188
Method	Price control		Quality control	
R-squared	.699		.937	
Observations	4001		4005	
Panel B: Markups	Est.	S.E.	Est.	S.E.
Average markdown	1.707	0.539	1.780	0.570
Average markup	0.879	0.458	0.789	0.504

Notes: The first two columns report the production function estimates when including a price control, the last two report the estimates with a quality control. Block-bootstrapped standard errors are computed with 200 iterations.

C.1.6 Intermediate input market power

Lamp oil prices

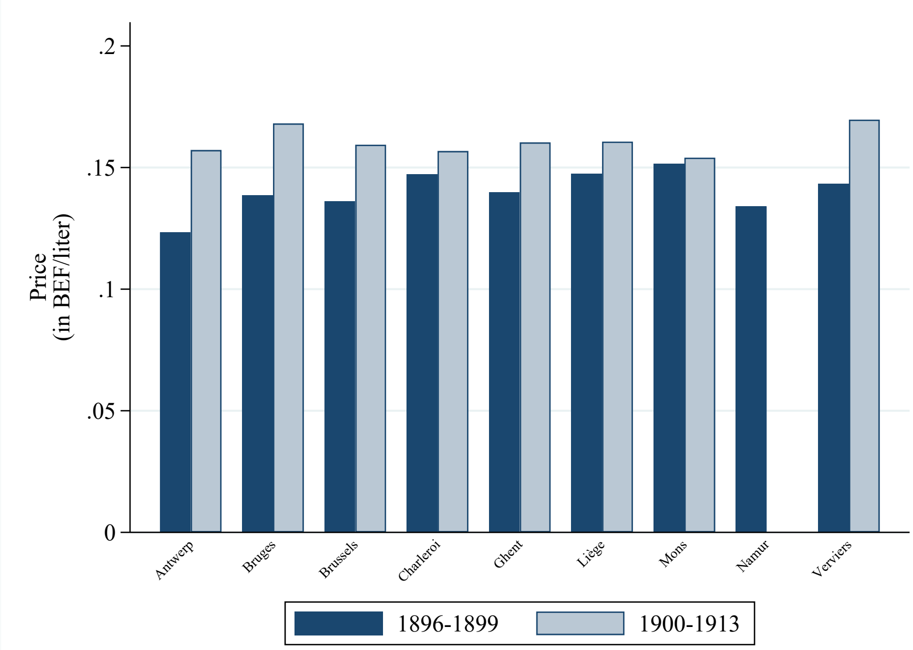
Our identification approach required exogenous intermediate input prices. We corroborate this assumption with further historical evidence. To do so, we collected monthly prices for *pétroleum* (lamp oil). Lamp oil was chosen because of data availability reasons, as well as its homogeneity allowing for straightforward regional comparison.[IX] This exercise results in a panel data set that covers all major urban and industrial centers in Belgium for the period 1896 to 1913.[X] As shown in Figure C.2, we find little regional variation in the prices of this input, both within mining areas (such as between Mons, in the west, and Liège, in the east) and across mining and non-mining centers (such as Bruges, Brussels, and Ghent). This lack of price variation could either imply a very competitive or a collusive market. After all, limited wage heterogeneity within labor markets was also used to motivate our labor supply model. However, the key difference is the size of the market. Lamp oil was used in both mining and non-mining regions, and prices are homogeneous at the national, not just the local level. Even under Cournot competition, lamp oil price markdowns would be close to zero because the lamp oil market shares of coal firms would be close to zero.

The evidence on lamp oil prices underlines that at least for one industrial input, Belgian markets were well-integrated, and intermediate input prices were probably exogenous to individual coal firms. One caveat in this analysis is that the quantitative importance of lamp oil as a cost share of intermediate input expenditure was likely very small. We cannot compute this cost share directly as the data by the *Administration des Mines* does not allow us to observe the cost share of lamp oil in materials. Moreover, the financial records in the company archives which we consulted in the state archives of Liège do not have the level of detail needed to dissect intermediate inputs into individual products. However, we can estimate this cost share by making some assumptions on lamp oil usage rates. We know how many oil lamps were in use: in January 1907, 41.597 oil-based lights were in use to support the works of the 30.314 underground workers active at the mines in our sample, so about 1.4 lamps per worker (interestingly, electrical lamps were still not introduced by then - in contrast to the mines in the province of Hainaut). We can also make the modest assumption that mine workers used about 5.2 liters of lamp oil on

[IX] Furthermore, from a *qualitative* perspective, lighting of the underground mine levels was definitely an important topic from both daily business and policy perspectives. The gaseous nature of Belgian mines meant that safe lighting was a challenging yet important step of the production process.

[X] This database is built on retail prices collected by the Belgian labor inspection services. Few wholesale prices survived for 19$^{\text{th}}$-century Belgium, and reconstructions are mostly based on nationally aggregated trade statistics (such as in Loots, 1936). Regional prices for earlier periods are even more scarcely available.

Figure C.2: **Average retail price for petroleum in major urban centers, 1896-1913**



Notes: Petroleum prices are plotted, based on monthly prices for the period 1896-1899 and on quarterly prices for the period 1900-1913.

Source: Data are adapted from the monthly publications by the Belgian *Office du Travail* (1896–1913), which collected monthly (quarterly from 1903) updates on the retail prices in Belgian urban centers.

a yearly basis.[XI] This allows us to estimate the yearly cost of lamp oil at mine level as: number of underground workers $\times 1.4 \times 5.2 \times$ lamp oil price per liter. Using yearly averages of the lamp oil price data we collected, we find an average firm-level lamp oil cost share of approximately 0.12% for the period of 1896 to 1913.

Revenue production function

Suppose firms would have had market power over intermediate inputs. This would imply a markdown of intermediate input prices, which we denote as $\mu_{ft}^{m} \equiv \frac{\frac{\partial R_{ft}}{\partial M_{ft}}}{W_{ft}^{m}} > 1$. The labor wage markdown formula becomes the following expression, which makes clear that ignoring market power over intermediate inputs leads to overestimating the

[XI]The lamp figures are based on own calculations using data from the following report: *Lampe de sûreté en usage dans les charbonnages de Belgique en janvier 1907* in *Annales des Mines de Belgique*, volume XII, published in 1907 (pp. 1075-1083). An average person is typically assumed to consume about 2.6 liters of lamp oil per year (for instance, see the Allen (2009) consumption basket). We multiplied this by 2 to account for the day-long darkness in underground mines.

wage markdown, when holding the production coefficients fixed.

$$\mu^l_{ft} = \frac{\theta^l \alpha^m_{ft}}{\theta^m \alpha^l_{ft} \mu^m_{ft}} \leq \frac{\theta^l \alpha^m_{ft}}{\theta^m \alpha^l_{ft}}$$

An alternative identification strategy that does not require the assumption of exogenous intermediate input prices is to estimate a revenue production function, rather than a quantity production function, as in Treuren (2022). Denoting the revenue elasticities as $\tilde{\beta}$ and revenue productivity as $\tilde{\omega}_{ft}$, the revenue production function to be estimated is:

$$r_{ft} = \tilde{\beta}^l l_{ft} + \tilde{\beta}^m m_{ft} + \tilde{\beta}^k k_{ft} + \tilde{\omega}_{ft}$$

As shown in Treuren (2022), the markup is no longer identified, but intermediate input and wage markdowns are separately identified:

$$\begin{cases} \mu^m_{ft} = \frac{\tilde{\beta}^m}{\frac{W^m_{ft} M_{ft}}{R_{ft}}} \\ \mu^l_{ft} = \frac{\tilde{\beta}^l}{\frac{W^l_{ft} L_{ft}}{R_{ft}}} \end{cases}$$

In the context of our paper, implementing this model poses some challenges and requires additional assumptions. First, as also pointed out by Treuren (2022), estimating this model requires observing intermediate input quantities m_{ft}, whereas we only observe intermediate input costs. In our main model, unobserved intermediate input price variation enters the residual, which is not a problem because these prices are assumed to be exogenous to the firm. As soon as these intermediate input prices are endogenous, however, this raises a simultaneity problem with the other inputs. Second, homogeneous revenue elasticity parameters $\tilde{\beta}$ imply a homogeneous coal price pass-through rate across firms, which is constant over time. This assumption, which is not necessary to estimate our baseline model, is likely invalid in our setting given the presence of a cartel. Finally, the revenue production imposes an AR(1) process on revenue productivity $\tilde{\omega}_{ft}$, rather than physical productivity ω_{ft}. This implies that prices also need to evolve as an AR(1), which is a stronger assumption than our baseline model and potentially violated due to entry into the cartel of some firms. In sum, we think the revenue production function approach is an interesting avenue to relax the exogenous intermediate input price assumption. However, we think that in the specific context of our paper, the additional assumptions required are less likely to be valid than the exogenous intermediate input price assumption.

In order to compare results, we estimate the revenue production function as a robustness check, using the GMM approach outlined in the main text, but using log revenues rather than log output as the left-hand side variable in the production function. The resulting estimates are summarized in the first column of Table C.5. Both the labor and material coefficients and the serial correlation of productivity are higher than in the quantity production function, and the output elasticity of labor is even estimated above one. We think that this could be due to the additional assumption of a homogeneous coal price pass-through, which is likely to be invalid in our setting. While we previously demonstrated that, when keeping production coefficients fixed, disregarding market power in intermediate inputs leads to an overestimation of wage markdowns and employer collusion, our findings change when using the revenue production function. In this scenario, wage markdowns appear larger because the output elasticity of labor is estimated to be substantially higher. The resulting collusion estimate is plotted as the purple triangles in Figure C.4 and lies above the collusion estimate in the main text. Although this collusion series peaks at multiple points before 1897, we still find a sustained increase in employer collusion after the coal cartel's introduction using this specification. The resulting collusion index is above one, which is not consistent with the theoretical model.

C.1.7 First differences

As a robustness check, we set the serial correlation in TFP to one: $\rho = 1$. This implies that we estimate the production function in first differences: this relies on the GMM estimator outlined in the main text, but setting $\rho = 1$ rather than estimating this serial correlation. The corresponding production function estimates are in the second column of Table C.5 and give higher output elasticities of labor and materials than in the main specification. The output elasticity of labor is even above unity. However, we do not put much trust in these estimates, given the unrealistic assumption of a unit root in total factor productivity. In most settings, including our baseline model, the serial

Table C.5: **Alternative production models**

Panel A: Output elasticities	log(Revenue)		log(Output)		log(Output)	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
log(Labor)	1.182	0.249	1.532	0.165	0.723	0.329
log(Materials)	0.528	0.105	0.522	0.092	0.186	0.181
log(Capital)	0.139	0.043	0.133	0.032	0.146	0.060
Serial correlation	1.001	0.072	1.000	0.000	0.846	0.146
Method	R.P.F.		$\rho = 1$		Time trend	
Hansen J-test	.522		4.54		4.16	
Hansen J-test p-value	.469		.208		.041	
Observations	4001		4005		4005	

Panel B: Markups	Est.	S.E.	Est.	S.E.	Est.	S.E.
Average markdown	1.972	0.412	1.684	0.335	2.231	3.030
Average markup	.	.	1.820	0.412	0.649	0.686

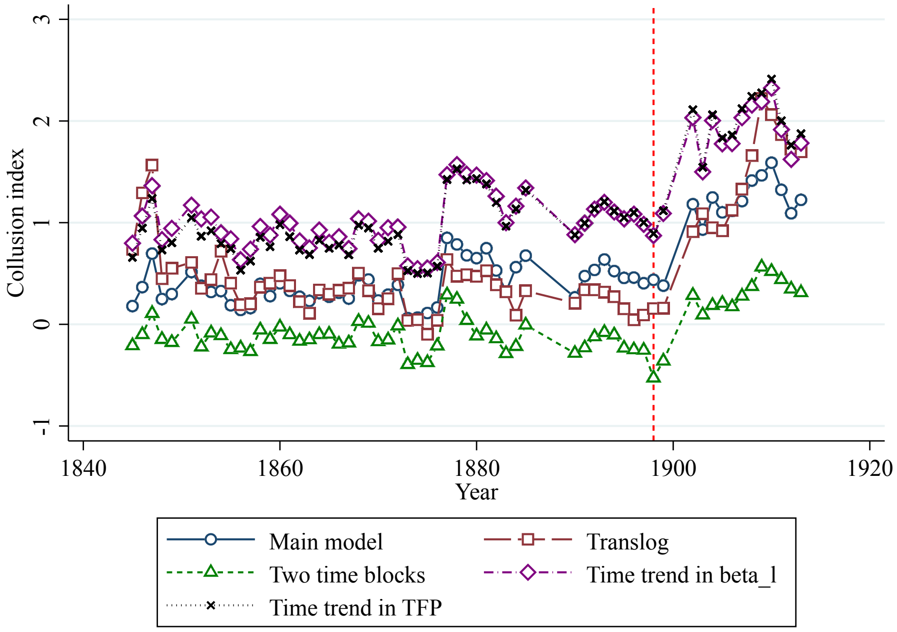
Notes: The first two columns report the estimates for a revenue production function. The middle two impose a serial correlation of one in productivity. The last two columns include a linear time trend in productivity. Block-bootstrapped standard errors, 200 iterations.

correlation of productivity is estimated to be below one, which implies a stationary productivity process. Nevertheless, as shown in the black crosses in Figure C.4, the corresponding collusion estimates are nearly identical to those in the main specification where ρ was not fixed to be equal to one.

Finally, it is also worth noting that misspecification of the serial correlation of TFP results in biased production function estimates. The TFP transition equation (2) specified the true TFP serial correlation ρ. Suppose that we estimate the production model using a different serial correlation $\tilde{\rho} \neq \rho$ in the moment conditions. Taking $\tilde{\rho}$ differences results in the following productivity shock term $\tilde{\upsilon}_{ft}$:

$$\tilde{\upsilon}_{ft} \equiv q_{ft} - \tilde{\rho} q_{ft-1} - \beta^0 (1-\tilde{\rho}) - \beta^l (l_{ft} - \tilde{\rho} l_{ft-1}) - \beta^m (m_{ft} - \tilde{\rho} m_{ft-1}) - \beta^k (k_{ft} - \tilde{\rho} k_{ft-1})$$
$$= (\rho - \tilde{\rho}) \omega_{ft-1} + \upsilon_{ft}$$

Figure C.3: **Collusion estimates: robustness checks (1)**



Notes: This graph shows the evolution of the median of our collusion measure, $\hat{\lambda}$, across the various production function robustness checks: (i) our model from the main text (ii) translog production function (Section C.1.3) (iii) time-varying production function with two time blocks (Section C.1.4) (iv) production function with a time trend in β^l (Section C.1.4) (v) production function with a time trend in ω_{ft} (Section C.1.4).

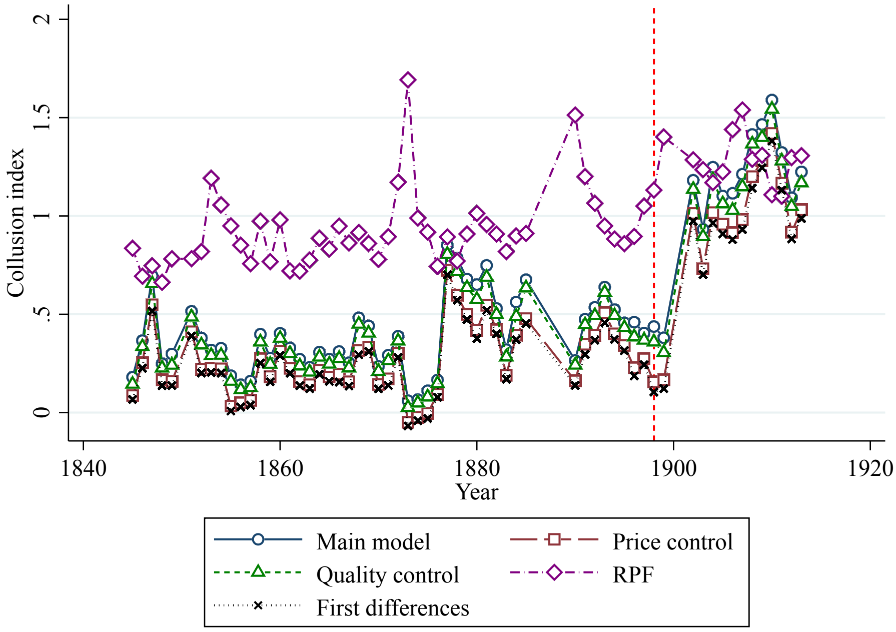
The moment conditions using the productivity shock $\tilde{\upsilon}$, rather than υ, is now given by Equation C.4. Using an incorrect serial correlation parameter no longer isolates the productivity shock υ_{ft} from the persistent component of TFP. Hence, as soon as $\rho \neq \tilde{\rho}$, the moment conditions become invalid, because lagged input choices l_{ft-1}, m_{ft-1}, and k_{ft-1} are correlated with lagged productivity ω_{ft-1}.

$$\mathbb{E}\Big[(\rho - \tilde{\rho})\omega_{ft-1} + \upsilon_{ft}|(l_{ft-1}, m_{ft-1}, k_{ft}, k_{ft-1}, w^{agri}_{t-1})\Big] \neq 0 \qquad \text{(C.4)}$$

C.1.8 Cost shares approach

As an alternative production function identification strategy, we rely on a 'cost shares approach' to estimate the output elasticities of labor and materials, as in Syverson (2004). In contrast to the production function estimation approach, the cost shares approach requires taking a stance on the size of the labor wage markdown. To see this, we solve the markup expressions $\mu_{ft} = \frac{\beta^l}{\alpha^l_{ft}\mu^l_{ft}}$ and $\mu_{ft} = \frac{\beta^m}{\alpha^m_{ft}}$ for the output elasticity of labor β^l. Denoting returns to scale parameter as $\varsigma \equiv \beta^l + \beta^m + \beta^k$ and assuming

Figure C.4: **Collusion estimates: robustness checks (2)**



Notes: This graph shows the evolution of the median of our collusion measure, $\hat{\lambda}$, across the various production function robustness checks: (i) our model from the main text (ii) production function with linear price controls (Section C.1.5) (iii) production function with quality controls (Section C.1.5) (iv) revenue production function (Section C.1.6) (v) production function in first differences (Section C.1.7).

variable capital with $w^k K$ being capital investment, the output elasticity of labor is equal to the *weighted* cost share of labor, weighting the wage bill by the markdown μ^l.

$$\beta^l = \varsigma\Big(\frac{W^l_{it} L_{it} \mu^l_{it}}{W^m_{it} M_{it} + W^k_{it} K_{it} + W^l_{it} L_{it} \mu^l_{it}}\Big)$$

If we make an assumption about the returns to scale parameter ς, we can estimate bounds on the output elasticity of labor β^l as the markdown-weighted cost share using the non-collusive and fully collusive wage markdown values $\underline{\mu^l}$ and $\overline{\mu^l}$ from the labor supply model. We estimate these output elasticities assuming constant returns to scale, $\varsigma = 1$, and take the median values of the cost share estimates of β^l across firms and years, as we still assume homogeneous output elasticities. The resulting estimates are reported in Table C.6. The average output elasticity of labor lies within the interval $\beta^l \in (0.65, 0.72)$, depending on the degree of collusion, whereas the average output elasticity of materials lies in $\beta^m \in (0.20, 0.26)$. The resulting average markup lies in the interval $\mu \in (0.61, 0.81)$. The estimated output elasticities for both variable inputs and the markup estimates in the main specification all lie within the bounds of the cost share-based estimates. The capital coefficient estimate in the main specification is larger than the estimate from the cost shares approach, which is logical given that capital is not a variable input.

Although the cost shares approach provides a useful test of the baseline model, and provides much more precise output elasticity estimates than the model in the main text, we do not use it as our baseline specification because the cost shares approach estimates the output elasticities under a specific conduct assumption, whereas the production function estimator in the main text does not do so. For our conduct identification approach, it is important to refrain from making conduct assumptions when estimating the production function, as our approach relies on comparing conduct-free markdown estimates from the production model to markdown estimates under specific conduct assumptions from the labor supply model.

Table C.6: **Production models with a cost shares approach: coefficients and markups**

Panel A: Output elasticities	Labor		Materials		Capital	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
Perfect collusion	0.722	0.030	0.203	0.027	0.075	0.011
No collusion	0.653	0.029	0.256	0.025	0.091	0.013
Panel B: Markup	Markup					
	Est.	S.E.				
Perfect collusion	0.614	0.034				
No collusion	0.806	0.078				

Notes: Panel A reports the estimated bounds on the output elasticities using the cost shares approach, under the assumption of perfect and no labor market collusion. Panel B reports the corresponding markup bounds. Block-bootstrapped standard errors are computed with 200 iterations.

C.1.9 Serial correlation in estimated productivity shocks

We test whether the productivity shock υ_{ft} is serially uncorrelated. We regress υ_{ft} on its lagged value υ_{ft-1} in panel A of Table C.7 and find a negative serial correlation of -0.204. This correlation is not significantly different from zero, so we cannot reject the null hypothesis of serially uncorrelated productivity shocks. As an additional robustness check and in order to relax the AR(1) assumption on the productivity process, we specify an AR(2) process as following:

$$\omega_{ft} = \rho_1 \omega_{ft-1} + \rho_2 \omega_{ft-2} + \upsilon_{ft}$$

This allows for Hicks-neutral productivity to be serially correlated with both its lagged and twice lagged value. These correlations are captured by the coefficients ρ_1 and ρ_2. Rewriting the moment conditions from Equation (16) and now using lags up to two years, the moment conditions are given by Equation (C.5).

$$\mathbb{E}\Big[q_{ft}-\rho_1 q_{ft-1}-\rho_2 q_{ft-2}-\beta^0(1-\rho_1-\rho_2)-\beta^l(l_{ft}-\rho_1 l_{ft-1}-\rho_2 l_{ft-2})-\beta^m(m_{ft}-\rho_1 m_{ft-1}-\rho_2 m_{ft-2}) \\ -\beta^k(k_{ft}-\rho_1 k_{ft-1}-\rho_2 k_{ft-2})|(l_{ft-1}, l_{ft-2}, m_{ft-1}, m_{ft-2}, k_{ft}, k_{ft-1}, k_{ft-2}, w_{t-1}^{agri}, w_{t-2}^{agri})\Big] = 0 \tag{C.5}$$

The production function estimates for the AR(2) model are in panel B of Table C.7. We obtain lower output elasticities for the variable inputs and a higher output elasticity of capital compared to the AR(1) model for TFP. The ratio of the variable inputs' output elasticities is of a similar magnitude to the main specification, which implies similar wage markdown and employer collusion estimates.

C.1.10 Extension to multi-product firms

In the main text, we specified a firm-level production function for a single-product firm. Rewriting Equation (1) in a more general form, we estimated a function $f(.)$ as written in Equation (C.6).

$$q_{ft} = f(l_{ft}, m_{ft}, k_{ft}; \boldsymbol{\beta}_f) + \omega_{ft} \tag{C.6}$$

Our method can be extended to a multi-product framework. Indexing products by j, a product-level multi-product production function can be specified as Equation (C.7).

$$q_{fjt} = f(l_{fjt}, m_{fjt}, k_{fjt}, \boldsymbol{q}_{f-jt}; \boldsymbol{\beta}_{fj}) + \omega_{fjt} \tag{C.7}$$

Table C.7: **Production model with serial correlation in productivity shocks: coefficients**

Panel A: Serial correlation of productivity shocks in AR(1) model	Productivity shock	
	Est.	S.E.
Lagged productivity shock	-0.204	0.148
Observations	8779	

Panel B: Production function coefficients in AR(2) model	log(Output)	
	Est.	S.E.
log(Labor)	0.598	0.163
log(Materials)	0.201	0.111
log(Capital)	0.355	0.129
One-year TFP correlation	1.365	0.263
Two-year TFP correlation	-0.407	0.181
Observations	3571	

Notes: Panel A reports the serial correlation in the estimated productivity shocks. Panel B re-estimated the model using an AR(2), rather than an AR(1) process for productivity. Block-bootstrapped standard errors are computed using 200 iterations.

The usual challenge applies that although quantities are often observed at the product-level, inputs rarely are. The literature has taken two approaches to estimate the production function: either disaggregate the firm-level inputs to the product-level (De Loecker et al., 2016; Dhyne, Petrin, Smeets, & Warzynski, 2022) or aggregate the production function to the firm level using a demand system, as in Orr (2022).

In the former approach, one in principle obtains a different wage markdown for every product, as the output elasticities are estimated differently for each product, with the important caveat that the input expenditures $W^m_{fjt}M_{fjt}$ and $W^l_{fjt}L_{fjt}$ are now estimated rather than observed. Hence, our approach will also deliver a different collusion estimate for every product. In contrast to product-specific markups, product-specific markdowns are counter-intuitive, as it would imply that firms have different degrees of market power when buying inputs for different products from the same supplier. Hence, imposing the additional assumption of homogeneous markdowns across products can provide over-identification to this model (for instance, to avoid having to impose at least one competitive input market).

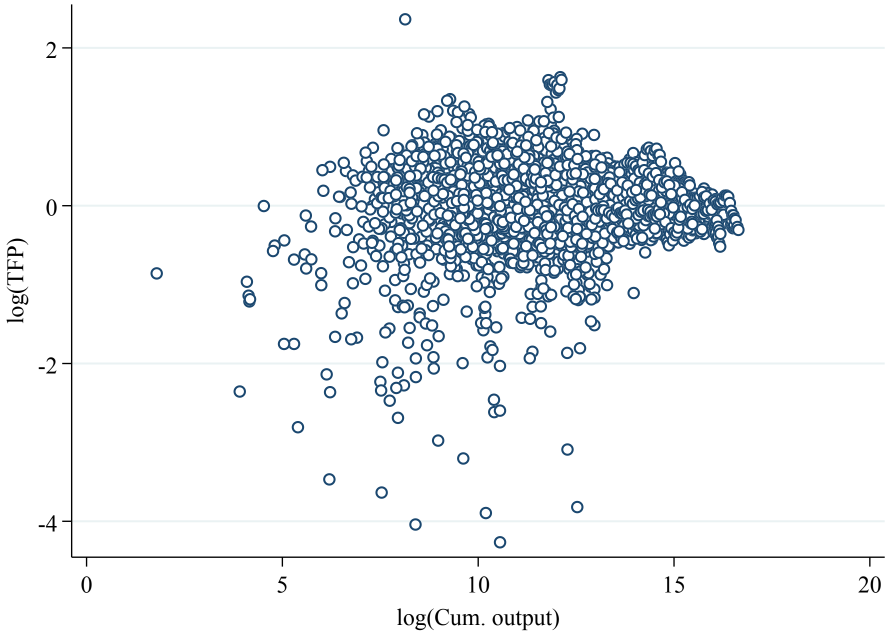
$$\mu^l_{fjt} \equiv \frac{\theta^l_{fjt} W^m_{fjt} M_{fjt}}{\theta^m_{fjt} W^m_{fjt} M_{fjt}} \tag{C.8}$$

In the latter approach of aggregating the multi-product production function to the firm level, the firm-level markdown and collusion estimation from the main text still applies as the output elasticities are estimated at the firm level, rather than at the product level. However, the cost minimization routine to infer input allocations, as in Orr (2022), would need to be adapted to allow for endogenous input prices. We leave this interesting challenge, which is beyond the scope of this paper, as a topic for future research.

C.1.11 Cost dynamics

One particular channel that could violate the AR(1) TFP transition assumed in the main text could relate to cost dynamics. As soon as current TFP is a function of cumulative lagged output, as in Benkard (2000), this would violate the AR(1) productivity transition. Mining costs that increase with depth could be causing such cost dynamics. To test this hypothesis, we plot log(TFP) against log cumulative past output in Figure C.5. No positive relationship emerges, in contrast to what would be expected if cost dynamics mattered.

Figure C.5: **Scatter plot of log TFP and log cumulative past output**



Notes: This figure plots log TFP and the log of cumulative past output across mine-year observations.

C.1.12 Production coefficients with different IV selections

In the main text, we included the lagged value of log agricultural wages as an additional instrument for estimating the production function. The main motivation for this instrument was the so-called 'agricultural invasion' of Wallonia: miners immigrated from the low-wage agricultural regions in the north of Belgium. Agricultural wage shocks, which could be the result of agricultural productivity shocks or variation in harvesting yields, act as labor supply shocks to the coal mines and can be used as an instrument for labor in the production function. However, one challenge could be that industrial productivity growth increases wages in agriculture, which could harm the exclusion restriction.

We address this challenge in two ways. First, we note that our production model is over-identified. We re-estimate the production function with the same instruments but exclude the agricultural wage instrument. Hence, we only rely on the timing assumptions to identify the production function. Omitting the wage instrument leads to non-convergence when using the derivative-based GMM estimation procedure used in the main text, so we estimate the exactly identified model with a derivative-free method: the Broyden–Fletcher–Goldfarb–Shanno algorithm. The results are in the second row of Table C.8. The output elasticities of labor and materials are more than twice as high as the coefficients when omitting the agricultural price instrument, which are reported in the first row. This is suggestive of a weak instruments problem. Without instrumenting, the output elasticities of the variable inputs are usually overestimated due to simultaneity bias. Weak instruments, hence, also lead to overestimated output elasticities, which seems to be the case when only relying on the input timing assumptions. Given that the markup is a function of the output elasticity of materials, the upward bias on the output elasticities results in an overestimated markup. This is less problematic for the markdown, as it divides the output elasticities of both variable inputs by each other.

The resulting markdowns and wage collusion series are of a lower magnitude than the model with the agricultural wage instrument, as shown in the red squares in Figure C.6, but the implications of the cartel for wage collusion remain intact. We keep the agricultural wage instrument for three reasons. First, we think it is good to provide additional labor supply shifters, rather than to only rely on the timing assumptions of the input decisions, as statistical power can be an issue in dynamic panel estimators. This seems to be the case in our application as well, given the unrealistically high output elasticities when not including the agricultural wage instrument. Second, the additional instrument provides a way to test for overidentifying restictions. Third, the GMM estimation routine that does not rely on the agricultural wage as an instrument has trouble converging with a derivative-based method, and even with a derivative-free method it sometimes does not converge in the different bootstrap iterations.

Furthermore, we re-estimate the production model while relying on shocks to Belgian agricultural wages. We include two drivers. First, we compute a measure of agricultural productivity in Belgium by dividing an agricultural production index from Gadisseur (1979) by linearly-interpolated agricultural employment from Buyst (forthcoming). This agricultural labor productivity series picks up both harvest shocks and the mechanization of the agricultural industry. Second, we collect data from the Belgian trade accounts, as adapted by Degrève (1982). We compute the log import price of four key agricultural products grown in Belgium, rye, wheat, oats, and barley, as defined as the logarithm of total import expenditure on these crops (in 1000 BEF) divided by the total import quantity (in 1000 kg). Belgian farmers faced increased

Table C.8: **Production models with different agricultural wage instruments: coefficients**

Panel A: Production coefficients	Labor		Materials		Capital	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
Additional instruments:						
Agricultural wage	0.699	0.338	0.222	0.141	0.153	0.074
No additional IV	1.475	0.211	0.586	0.119	0.153	0.038
Ag. wage drivers	1.192	0.327	0.401	0.141	0.162	0.066

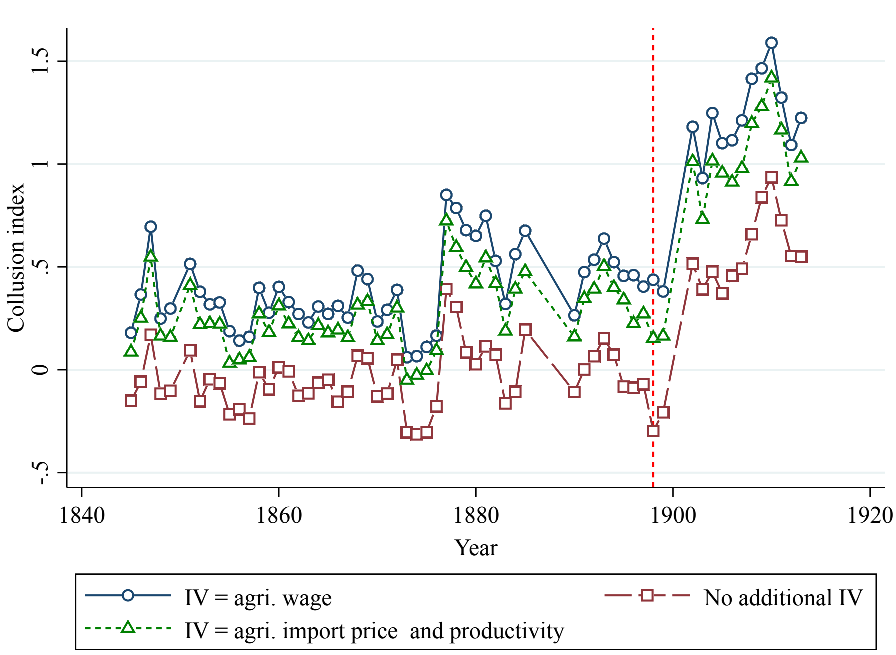
Panel B: Ag. wage drivers	log(Ag. wage)	
	Est.	S.E.
Ag. labor productivity	-0.129	0.079
Ag. import price	0.270	0.056
R-squared	.925	
Observations	58	

Notes: Panel A reports the production coefficients when using the agricultural wage instrument (as in the main text), no additional instruments, and the agricultural wage drivers, being agricultural productivity and the import price of key grains. Panel B regresses the log Belgian agricultural wage index on log agricultural labor productivity and the log agricultural import price for the grains, controlling for a linear time trend and the log aggregate import price index. Standard errors (S.E.) in panel A are block-bootstrapped with 200 iterations, S.E. in panel B are heteroskedasticity-robust.

international competition, notably from the U.S. (for an appraisal, see O'Rourke, 1997; for a Belgian perspective, see Blomme, 1992, 289-292). Agricultural import price shocks are labor demand shocks for Belgian farmers and, hence, labor supply shocks for Belgian coal mines. In panel B of Table C.8, we confirm this mechanism by regressing log agricultural wages on both log agricultural productivity and log grain import prices. We control for a linear time trend and the log of aggregate import prices. The results confirm that agricultural productivity shocks increased Belgian agricultural wages. Grain import prices also increased Belgian agricultural wages: as import prices fell, demand for Belgian agricultural products decreased, which depressed agricultural wages in Belgium.

We carry out the robustness check by adding both lagged log agricultural productivity and the lagged log agricultural import price measure as additional instruments to the production function, rather than agricultural wages. The resulting production coefficients are in the third row of Table C.8. Both the labor and materials coefficient are again estimated at a higher level compared to the main specificiation, but the difference is smaller than when not including any additional instruments. This suggests that there is still a weak instruments problem when relying only on the underlying drivers of agricultural wages, rather than on the agricultural wage series itself. However, we note that the corresponding wage collusion series, the green triangles in Figure C.6, is still very similar to the main specification.

Figure C.6: **Collusion estimates with different IV selections**



Notes: This figure compares the evolution of median employer collusion using the following instruments in the production function estimation, on top of the lagged and current input usage: (i) agricultural wages (i.e., the main specification) (ii) no additional IV, and (iii) the agricultural import price and agricultural productivity.

C.2 Labor supply: extensions and robustness

C.2.1 Wage variation and firm fixed effects

In Table C.9, we regress log miner wages and log wage markdowns on year fixed effects (in column 1), year and municipality fixed effects (in column 2), and year, municipality, and firm fixed effects (in column 3). Year fixed effects explain 87.6% of the variation in wages. Adding municipality fixed effects increases the R^2 to 92.7%. Finally, adding firm fixed effects increases the R^2 further to 94.4%. The additional R^2 due to firm fixed effects is, hence, explained by the municipalities for 75%, and by the firms, conditional on the municipalities, for 25 %.

Table C.9: **Wage variation across and within markets**

	R^2	R^2	R^2
log(Wage)	0.876	0.927	0.944
log(Wage markdown)	0.109	0.238	0.397
Year F.E.	X	X	X
Municipality F.E.		X	X
Firm F.E.			X

Next, we assess the variation in the firm fixed effects. Denoting the number of firms as F and firm fixed effects in the log wage regression as γ_f, we estimate a bias corrected standard deviation of the firm fixed effects as the square root of the variance of the fixed effects, from which we subtract the squared average standard error on the fixed effect estimates $\hat{\gamma}_f$. This bias-corrected standard deviation $\tilde{sd}_f$ is equal to 0.397 log points. The small size of the standard deviation of the firm fixed effects is another reason to suspect that firm differentiation is not key in our labor supply model.

$$\tilde{sd}_f = \sqrt{Var(\hat{\gamma}_f) - \frac{1}{F}\sum_f (se(\hat{\gamma}_f)^2)}$$

C.2.2 Test for employer differentiation

In addition to the discussion of wage variation in the previous section, we provide a more formal test of employer differentiation. We re-estimate the labor supply equation from Equation (3) at the firm level, as opposed to the market-level regression in the main text. First, we estimate it without including any fixed effects, in Equation (C.9a). Second, we add labor market-by-year fixed effects, in Equation (C.9b).

$$w_{ft} = \psi l_{ft} + \ln(\nu_{ft}) \tag{C.9a}$$

$$w_{ft} = \psi l_{ft} + \ln(\nu_{ft}) + \delta_{it} \tag{C.9b}$$

We instrument employment using the same labor demand shifters as above: the 1870 international coal price hike and cartel membership after the introduction of the cartel. This is a test of employer differentiation: the labor supply function should be upward-sloping when not including any fixed effects as this is tracing out a market-level labor supply elasticity. However, as soon as we rely only on within-market wage variation, the labor supply function should be flat if employers are homogeneous.

The left column of Table C.10 shows that the inverse labor supply elasticity is 1.296 when estimating labor supply without any fixed effects. However, as soon as market-by-year fixed effects are included, the firm-level elasticity becomes slightly negative and no longer statistically different from zero. Based on within-market employment variation only, the firm-level labor supply curve is no longer upward-sloping, which supports the employer homogeneity assumption.

Table C.10: **Test for employer differentiation**

	log(Wage)		log(Wage)	
	Est.	S.E.	Est.	S.E.
log(Employment)	1.296	0.214	-0.043	0.109
Market-Year FE	No		Yes	
First-stage F-statistic	265		46.1	
Observations	4808		3982	

Notes: Robust standard errors are included.

C.2.3 Differentiated employers models

In the model of the main text, we assumed that employers are not differentiated from the workers' perspectives. As a robustness check, we specify a differentiated employers model. We rely on a logit utility function as in Berry (1994) and Azar et al. (2022). We specify two alternative functional forms for the utility of workers j. First, we rely on a linear wage utility model for workers, in Equation (C.10a). Firms are differentiated through an amenity term a_{ft}. We rely on the usual logit assumption for the worker-firm specific utility term ϵ_{jft}.

$$U_{jft} = \alpha w_{ft} + a_{ft} + \epsilon_{jft} \tag{C.10a}$$

As a second specification, we use a log-linear wage utility model for workers j, in Equation (C.10b). This implies that worker utility is concave in wages.

$$U_{jft} = \alpha \ln(w_{ft}) + a_{ft} + \epsilon_{jft} \tag{C.10b}$$

Third, we also impliment a log-linear wage utility model with a constant alternative wage $b > 0$ following Card et al. (2018), in Equation (C.10c).

$$U_{jft} = \alpha \ln(w_{ft} - b) + a_{ft} + \epsilon_{jft} \tag{C.10c}$$

Workers are assumed to choose between all firms in their labor market in each year, with $f = 0$ indicating the outside option of working in a different industry than coal mining or not working at all. F_{it} denotes the number of coal firms in each market i. Differentiated employers simultaneously set wages to minimize costs, which implies Nash-Bertrand wage-setting. The labor market share of employers is denoted s^l_{ft}, which is the employment share of firm f in the total market including the outside option. The outside option market share is denoted as $s^0_{i(f)t}$.

$$s^l_{ft} \equiv \frac{L_{ft}}{\sum_{g=0,1,\ldots,F_{it}}(L_{gt})}$$

The corresponding markdowns are given by Equation (C.11a) for the linear utility case, by Equation (C.11b) for the concave utility case, and by Equation (C.11c) for the concave utility with outside option case.

$$\psi^l_{ft} = 1 + (\alpha w_{ft}(1 - s^l_{ft}))^{-1} \tag{C.11a}$$

$$\psi^l_{ft} = 1 + (\alpha(1 - s^l_{ft}))^{-1} \tag{C.11b}$$

$$\psi^l_{ft} = 1 + (\alpha \frac{w_{ft}}{w_{ft} - b}(1 - s^l_{ft}))^{-1} \tag{C.11c}$$

Following Berry (1994), we estimate the labor supply function using Equation (C.12a) for the linear utility model, Equation (C.12b) for the concave utility model, and Equation (C.12c) for the concave utility model with an alternative wage option. We define the total labor market size as the municipal population between 15 and 55 years. We obtain population data from the Belgian population censuses of 1866, 1880, 1890, and 1900. We linearly interpolate the populations for the intermittent years. The outside option is, hence, given by the working population minus the workforce employed in coal mining.

$$\ln(s_{ft}) - \ln(s^0_{i(f)t}) = \alpha w_{ft} + a_{ft} \tag{C.12a}$$

$$\ln(s_{ft}) - \ln(s^0_{i(f)t}) = \alpha \ln(w_{ft}) + a_{ft} \tag{C.12b}$$

$$\ln(s_{ft}) - \ln(s^0_{i(f)t}) = \alpha \ln(w_{ft} - b) + a_{ft} \tag{C.12c}$$

We estimate Equations (C.12b) and (C.12a) using the same demand shifters as instruments as were used in the Cournot model: the international price shock after 1870 and the cartel membership indicator after the start of the cartel. The resulting estimates for the labor supply coefficients and the lower-bound markdowns can be found in Table C.11.[XII] For the loglinear utility model with alternative wage, (C.12c), our estimator does not converge with the two previously used instruments. Hence, we include the log import price of coal as a third instrument. The underlying exclusion restriction implies that individual Belgian coal operators cannot influence the world price of coal, which is reasonable given that their market shares of the global coal market are small.

In both labor supply specifications without an alternative wage option, we find a significant wage coefficient, which implies an upward-sloping labor supply curve to each firm. In the model with alternative wage, the wage coefficient is estimated imprecisely and is not significantly different from zero. The alternative wage b is estimated to be 0.525 BEF, which is 20% of the average wage and two thirds of the bottom percentile wage. However, this alternative wage parameter is also imprecisely estimated.

The corresponding average wage markdown ratio is 2.6 for the linear worker utility model, 2.3 for the loglinear worker utility model, and 2.0 for the loglinear model with alternative wage. These wage markdowns are substantially above the markdowns found in the production model, and they are, in most years, even above the fully collusive markdown in the Cournot model. Figure C.7 plots the median ratio of the production markdown over the non-collusive lower markdown bound in the four spec-

[XII] In principle, the upper markdown bounds can also be computed using the Bertrand model. This requires solving for the equilibrium wages and market shares at all firms under the identity ownership matrix. Given that we only present the Bertrand model as a robustness check for comparison purposes, we do not carry out this exercise. We restrict our comparison to the lower markdown bounds, which can be readily computed using the observed, rather than counterfactual, wages and market shares.

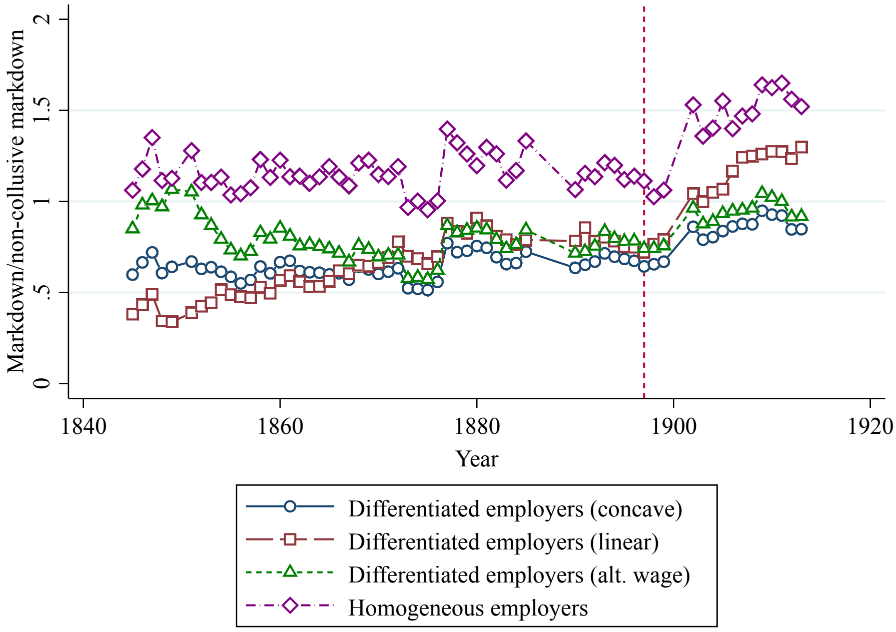
ifications: the Cournot model and the Bertrand models with linear utility, loglinear utility, and loglinear utility with alternative wage. As was explained in the main text, the median wage markdown is twice the size of the non-collusive Cournot markdown, which points to wage collusion. In the linear utility Bertrand model, the production markdown is below the non-collusive lower bound until 1901, which cannot be reconciled with economic theory. We still notice an important increase in the production markdown relative to the non-collusive Bertrand markdown after the introduction of the cartel. For the loglinear utility model, the median markdown is below the non-collusive lower bound in almost every year. The production-based wage markdowns are, hence, not in line with the Bertrand wage markdown bounds. This gives reason to reject the differentiated employers Bertrand model, under the assumption that the production-based markdowns are the true markdowns. Finally, for the loglinear model with alternative wage, the median markdown is also below the non-collusive lower bound for all years except in the 1850s and after 1900. Again, the relative markdown increase after the cartel's introduction still holds under this specification.

Table C.11: **Labor supply models with differentiated employers: coefficients and non-collusive markdowns**

Panel A: Labor supply	Linear U.		Concave U.		Alt. wage	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
Wage coefficient, α	0.308	0.057	0.740	0.125	0.525	0.800
Outside option, b					0.641	2.124
Observations	4594		4593		4360	
Panel B: Markdown	Linear U.		Concave U.		Alt. wage	
	Average	Median	Average	Median	Average	Median
Non-coll. markdown $\underline{\mu}^l$	2.617	2.363	2.447	2.393	2.015	2.058

Notes: Panel A reports the estimated coefficient on the wage and the log wage in the linear and loglinear labor supply models. Robust standard errors are included. Panel B reports the corresponding average and median wage markdowns in the absence of collusion.

Figure C.7: **Collusion estimates with differentiated employers**



Notes: This figure plots the median ratio of the wage markdown over the non-collusive lower bound of the markdown in three labor supply models: (i) the Bertrand model with loglinear labor utility, (ii) the Bertrand model with linear labor utility, and (iii) the Cournot model from the main text.

C.2.4 Time-varying labor supply elasticity

In this robustness check, we examine whether the wage coefficient in the labor supply equation, Equation (3), might have changed over time. In contrast to the production model, we cannot separately estimate the labor supply model during different time blocks because the instruments rely on variation that takes place after 1870: the international price shock in 1871 and the cartel in 1898. However, we can estimate a model that allows for a selection of coefficients to change over time, keeping all other labor supply coefficients constant. We split the panel in two and denote the first time period as $I(t < 1880)$. We specify two labor supply specifications. First, in Equation (C.13a), we allow the labor supply elasticity to be time-varying. The resulting labor supply elasticity is given by $\Psi^l = \Psi^l_1 + \Psi^l_2 I(t < 1880)$.

$$w^l_{it} = \Psi^l_1 l_{it} + \Psi^l_2 l_{it} I(t < 1880) + \Psi^l_3 I(t < 1880) + \nu_{it} \tag{C.13a}$$

Second, in Equation (C.13b), we allow the labor supply residual to be time-varying by including a linear time trend in the labor supply equation.

$$W_{it}^{l} = L_{it}^{\Psi^l} + \Psi^t t + \nu_{it} \tag{C.13b}$$

Third, in Equation (C.13c), we allow the labor supply elasticity to evolve linearly over time by interacting the employment coefficient with a linear time trend:

$$w_{it}^{l} = \Psi^l l_{it} + \Psi^{lt} l_{it} t + \Psi^t t + \nu_{it} \tag{C.13c}$$

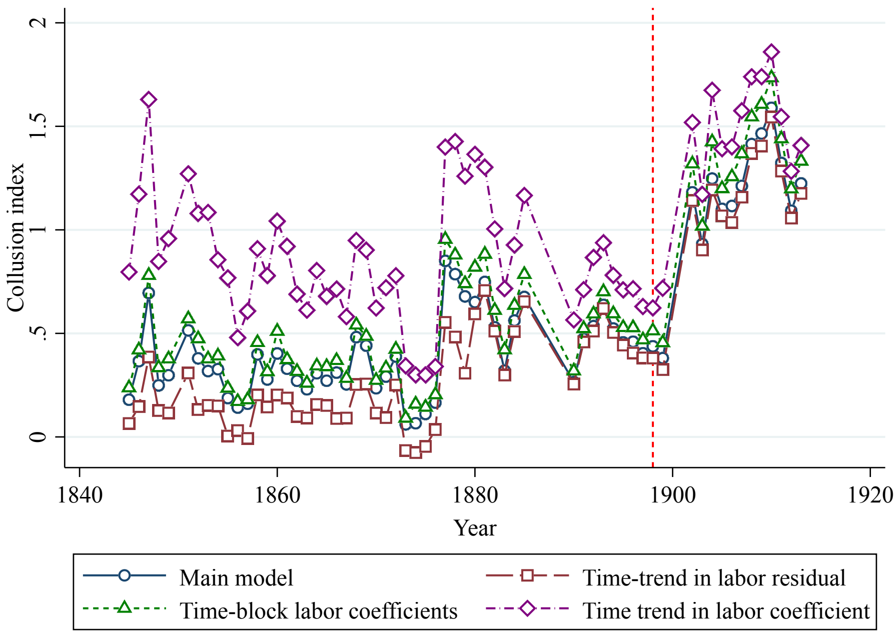
We present the resulting labor supply coefficients for these three specifications in Table C.12. The time block-specific labor supply model and the model with a time trend in the labor supply residual both imply a very similar evolution of employer collusion as the main specification, as can be seen in Figure C.8. The model with a time trend in the labor coefficient results in substantially higher collusion estimates, with peaks above one prior to the cartel period. However, this specification also finds a sustained increase in employer collusion after the cartel introduction.

Table C.12: **Labor supply models with time-varying coefficients: coefficients**

	log(Wage)		log(Wage)		log(Wage)	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
log(Employment) (1845-1879)	1.383	0.323				
log(Employment) (1880-1913)	1.034	2.920				
log(Employment)			0.941	0.310	-10.123	9.710
Year			0.002	0.007		
log(Employment)*Year					0.006	0.006
Observations	784		1990		1990	

Notes: The first two columns estimate the labor supply elasticity for two equally-sized time blocks. The second pair of columns includes a linear time trend in the labor supply residual. The third pair of columns allows for a linear time trend in the market-level labor supply elasticity. Robust standard errors are included.

Figure C.8: **Collusion estimates under time-varying labor supply coefficients**



Notes: This figure reports the median employer collusion index for the three specifications with time-varying labor supply functions.

C.2.5 Labor market definitions

In the main text, we defined labor markets at the municipality level. The expansion of the railroad and tramway network could threaten the validity of this market definition. Figure D.6 in Appendix D.2 shows that the railroad network expanded mainly from the 1840s to the 1870s. By 1880, all villages in our data set were connected to the railroad network. Starting in the 1880s, a local tramway network was added, which increased commuting options for workers who lived far from the local train station.

To check the sensitivity of our markdown estimates to this expansion in transport infrastructure, we examine whether wage markdowns differed in villages that were connected to the railroad or tramway network, given that 10% of workers commuted between 10 and 60 km, which indicates the usage of trains or tramways. As shown in Table C.13, we do not find that wage markdowns differed between villages connected to transport infrastructure and unconnected villages, and we find no difference between urban and rural municipalities.

These estimates suggest that not taking into account changing commuting options when defining labor markets is not a key issue in the context of our paper. Nevertheless, it could be the case that we defined labor markets too narrowly or too broadly.

Table C.13: **Markdown correlates**

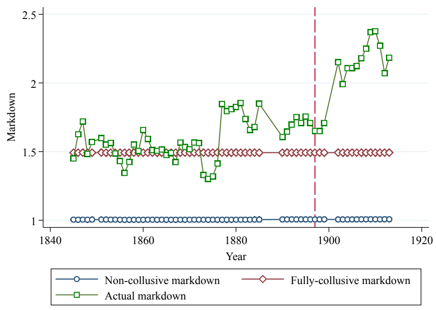
	log(Markdown)		log(Markdown)	
	Est.	S.E.	Est.	S.E.
1(Railroad)	-0.009	0.055	-0.001	0.049
1(Tramway)	-0.059	0.053	0.026	0.064
1(Urban)	0.066	0.044	0.000	0.000
One firm	0.069	0.220	0.091	0.138
Two firms	0.102	0.082	0.144	0.078
Three firms	0.032	0.082	0.049	0.068
Mine FE	No		Yes	
Year FE	Yes		Yes	
R-squared	.124		.129	
Observations	3221		3221	

Notes: This table regresses mine-level wage markdowns on connectedness to the public transportation network, and the number of firms in the municipality. Block-bootstrapped standard errors are computed with 200 iterations.

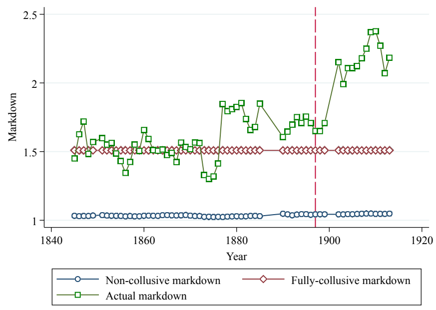
In order to check the robustness of our results, we re-estimate the lower and upper markdown bounds under zero and full collusion at different market definitions. In Figure C.9, we define labor markets consecutively at the single-digit postal code level, which corresponds to provinces, and the two-, three-, and four-digit postal code levels. The four-digit postal code level corresponds to municipalities, which is the market definition in the baseline specification. At the one- and two-digit levels, labor markets are so wide that individual firms have close to zero market shares, which implies that the non-collusive markdown in the Cournot model is close to one: individual firms have no wage-setting power. Using these market definitions, firms were already fully colluding on the labor market prior to forming the cartel and were reaching a markdown above the collusive upper bound after the cartel. Contrary to this, defining labor markets at the three-digit level, which corresponds to groups of three to five municipalities, delivers very similar markdown bounds to those in the baseline specification.

Figure C.9: **Median employer collusion index: different market definitions**

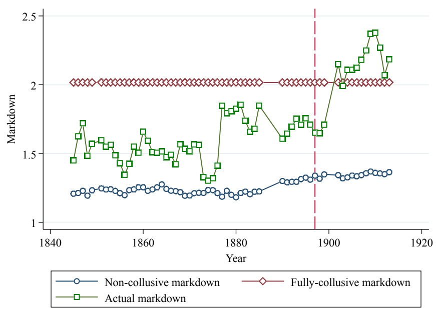
(a) **1-digit (Province) level**



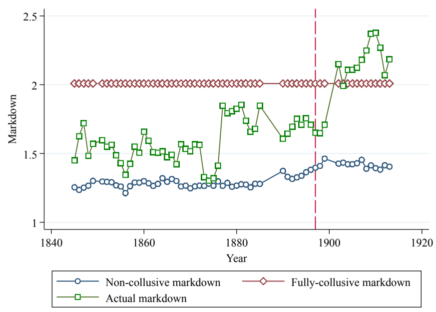
(b) **2-digit level**



(c) **3-digit level**



(d) **4-digit (Municipality) level**



Notes: This graph plots the evolution of median wage markdowns and the lower and upper markdown bounds under no and full collusion for four labor market definitions: one-, two-, three-, and four-digit postal code areas.

C.2.6 Different definition of the labor demand shock

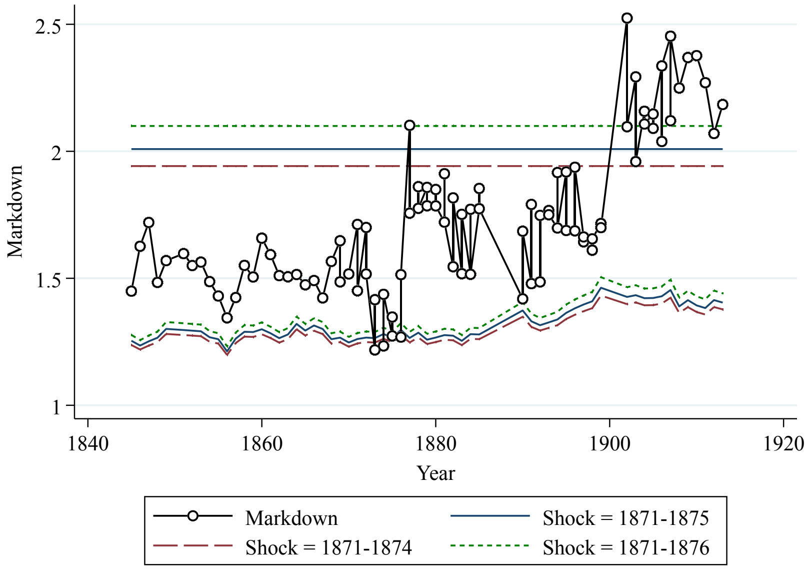
In the main text, we defined the labor demand shock due to the international coal price surge after the Franco-Prussian war as the period 1871-1875. This definition was done based on the price hike seen in Figure 2. As a robustness check, we re-define this labor demand shock as the period 1871-1874 and 1871-1876. Figure C.10a shows that this delivers very similar markdown bounds.

C.2.7 Different instrument selection

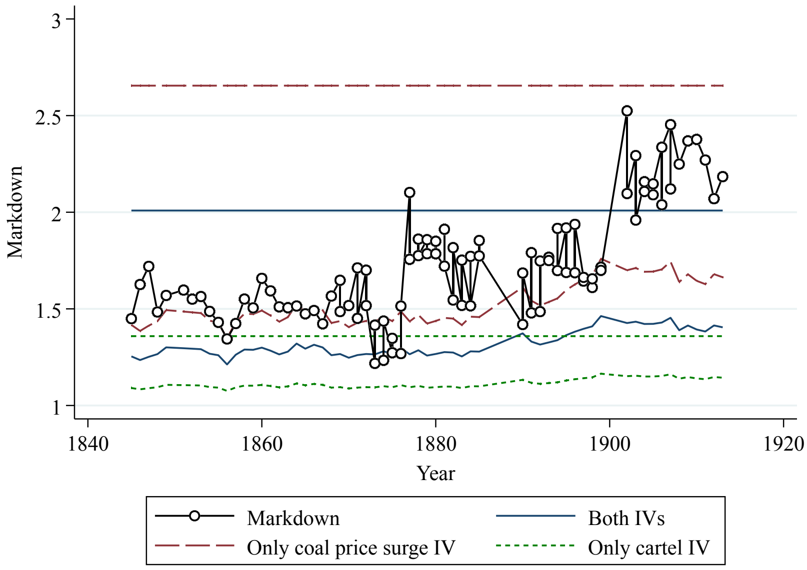
The overidentification test for the labor supply model in the main text rejected overidentifying restrictions. As a robustness check, we re-estimate the model using only the post-war coal price hike and the cartel introduction, interacted with cartel membership, as instruments. The corresponding markdown bounds are shown in Figure C.10b. When only relying on the coal price surge as an instrument, we find a higher markdown bound, and the cartel leads to an increase of markdowns from being equal to the non-collusive lower bound to being around half of the fully collusive level. When only using the cartel membership information as an instrument, we obtain lower markdown bounds: even prior to the cartel, markdowns are above the fully collusive bound. We continue to use both labor demand shocks as instruments in the main specification in the paper because this allows us to incorporate both inter-temporal and cross-sectional labor demand variation in the instruments. The coal price surge provides us with a large intertemporal labor demand shock, whereas the cartel membership dummy mainly provides cross-sectional labor demand variation. We rationalize the difference in estimates between these different instruments as tracing out labor supply elasticities that are short-term elasticities (for the price surge instrument) and long-term elasticities (for the cartel membership instrument).

Figure C.10: **Lower-bound and upper-bound markdowns: other robustness checks**

(a) **Alternative labor demand definition**



(b) **Alternative IV selection**



Notes: Figure (a) compares markdowns and markdown bounds under no and full collusion when widening and narrowing the coal price hike period by one year. Figure (b) plots markdowns and markdown bounds in the main model specification, the model specification where only the coal price hike is used as an instrument, and the specification where only the cartel participation is used.

C.3 Other robustness checks

C.3.1 Compensating differentials

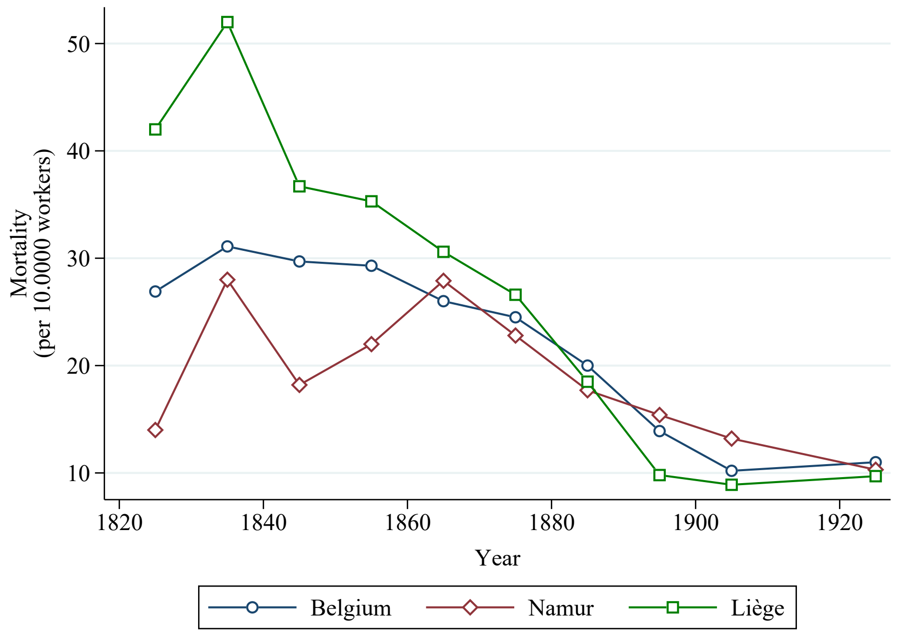
Another possible driver of the long-run evolution of markdowns are changes in compensating differentials due to changes in mining risk. Such compensating differentials are embedded in the amenity terms a_{ft} in the differentiated employers model of Appendix C.2.3. Still, we note that the nature of work changed substantially throughout 19^{th}-century industrialization, and it could be that the documented long-run pattern of markdowns reflects these changes. We rely on observed wages but do not take into account an implicit risk premium. Changes in wages due to changes in the underlying risk premium would be interpreted as changes in markdowns in our model.[XIII] One specific dimension which merits attention in this context is the role of worker safety. Coal mining was a notoriously dangerous profession in that era, and coal firms have been found to provide some compensation to their workers for these professional hazards (Fishback, 1992, 125).

Could drastic changes in mine safety explain the markdown estimates as documented in this paper? In Figure C.11, we reconstruct the safety record of Liège-based coal mines in terms of fatal casualties for the long 19^{th} century. From a Belgian perspective, mines in Liège were relatively dangerous because of their geological composition, with narrow coal veins. Throughout the second half of the century, however, working conditions improved substantially. This pattern, which matches the European picture, was supported by considerable investments in improved lighting and mechanical ventilation (Murray & Silvestre, 2015).[XIV] Crucially, most of these developments were completed before the end of the century. This means that the rise in markdowns we document in the early 20^{th} century is unlikely to have been imposed on workers to make them pay for the cost of these safety-oriented investments.

[XIII] A similar argument has been raised in the living standards debate, in which pessimistic appraisals underlined that optimistic conclusions regarding 18^{th}- and 19^{th}-century wage growth failed to acknowledge the negative impact of industrialization on non-wage working and living conditions (for a recent overview and comprehensive analysis, see Gallardo-Albarrán & de Jong, 2021).

[XIV] We also provided evidence of this in Figure D.5a.

Figure C.11: **Number of fatal casualties in Belgium-, Liège- and Namur-based coal mining (per 10.000 workers), 1821-1930**



Notes: Plotted are the decadal averages in coal mine fatalities. No data is included for the period 1910-1920.

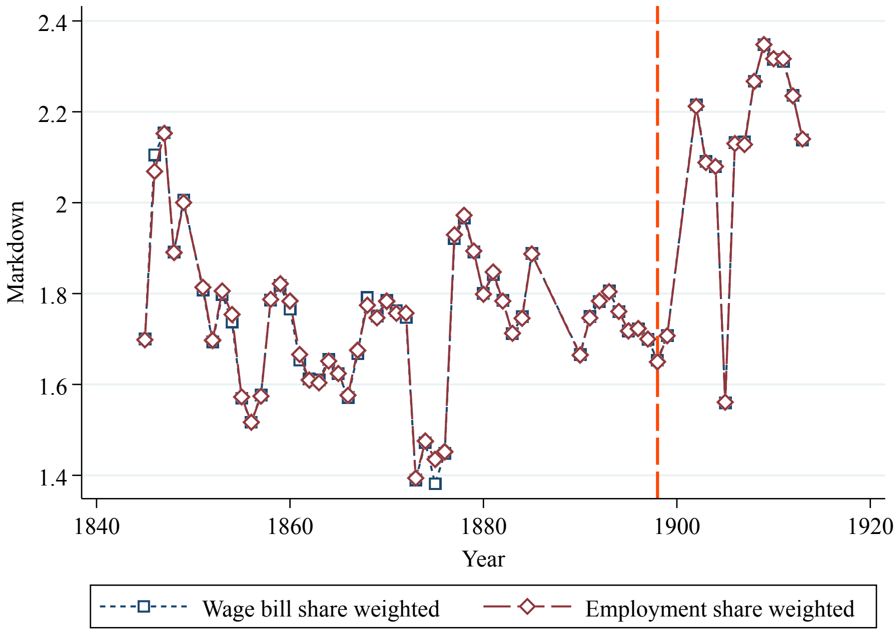
Source: Coal mining accident data and employment are from the published accounts of the *Administration des Mines*, as cited in Leboutte (1991).

C.3.2 Aggregation

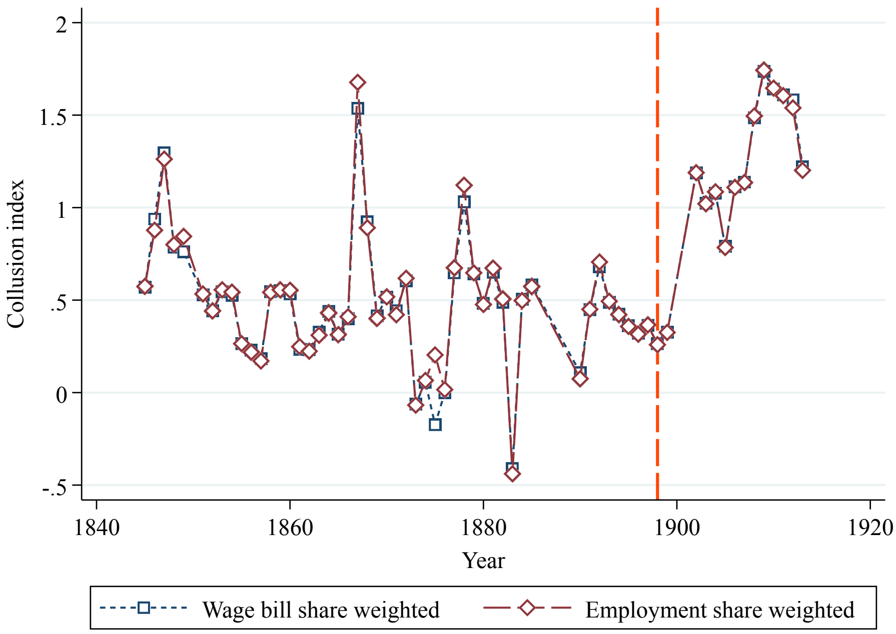
In the main text, we aggregate markdowns and collusion indices by taking employment share-weighted averages. When weighting by wage bill shares, we obtain very similar results. Figure C.12 shows the aggregated markdowns using weights based on wage bill shares and employment shares. Figure C.12b does the same for the employer collusion measure. We find that the series are very similar, independently of the chosen weights.

Figure C.12: **Aggregation of wage markdowns and collusion estimates: use of wage bill vs. employment shares**

(a) **Wage markdown**



(b) **Collusion estimates**



Notes: Figure (a) compares the aggregate wage markdown evolution when weighting by wage bill shares and by employment shares. The dashed vertical line represents the start of the coal cartel, the *Syndicat de Charbonnages Liégeois*. Figure (b) does the same for the employer collusion estimates.

C.3.3 Political changes and democratization

The social movements of the final decades of the 19$^{\text{th}}$ century were successful in increasing political participation among workers in Belgium. From Belgium's inception in 1830, voting rights were distributed according to a system of census suffrage, in which only the wealthiest - about 7% of the adult male population on average - were able to vote (Stengers, 2004, 249). This was undoubtedly a contributing factor to Belgium's total commitment to a *laissez-faire* policy stance regarding labor and social issues. The emergence of the Belgian socialist party *Parti Ouvrier Belge* (POB) as well as increasing progressive voices within the liberal and catholic parties paved the way towards universal suffrage, although with plural voting rights such that the highest taxpayers maintained a disproportionate amount of political control.

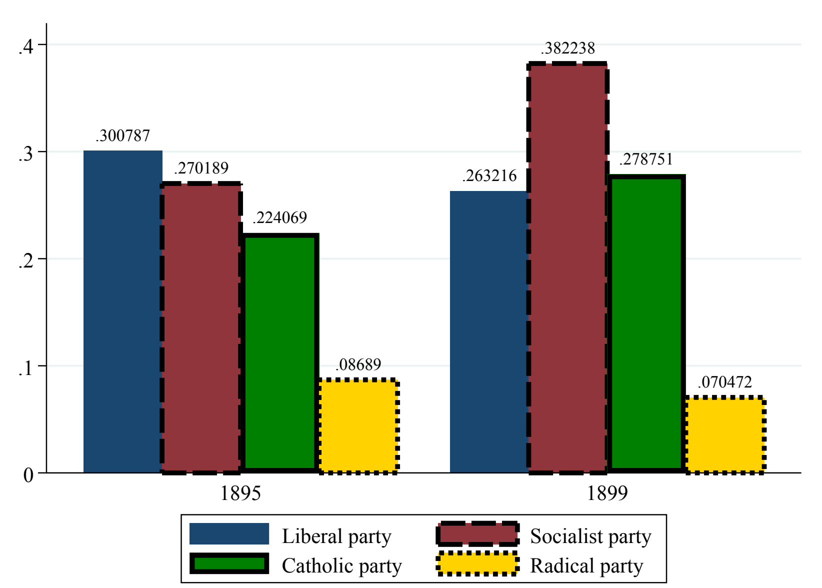
Figure C.13a documents the voter shares of the first two elections at the community level with universal suffrage, showcasing the popularity of the new POB within the Liège and Namur industrial areas. The question is now whether this growing political emancipation of the working class translated into improvements of the workers' bargaining position. In Figure C.13b, we provide a tentative answer to this complicated question. We compare the evolution of employer collusion in socialist-dominated communities with those in which other parties had a political majority. It is apparent that socialist rule was not able to counter the documented upswing in employer collusion, with both groups of municipalities experiencing a similar structural break in our collusion estimates after the cartel introduction in 1897.

Two caveats are to be placed with this tentative analysis. First, we forego the fact that other traditional parties also adapted their program to cater to the increasing demand for social policies.[XV] This limits the validity of this counterfactual analysis, and monopsony and employer collusion could have even surged more in the absence of this emerging labor movement. Second and more importantly, many of the demands by the emerging labor movement would only be made a reality after the First World

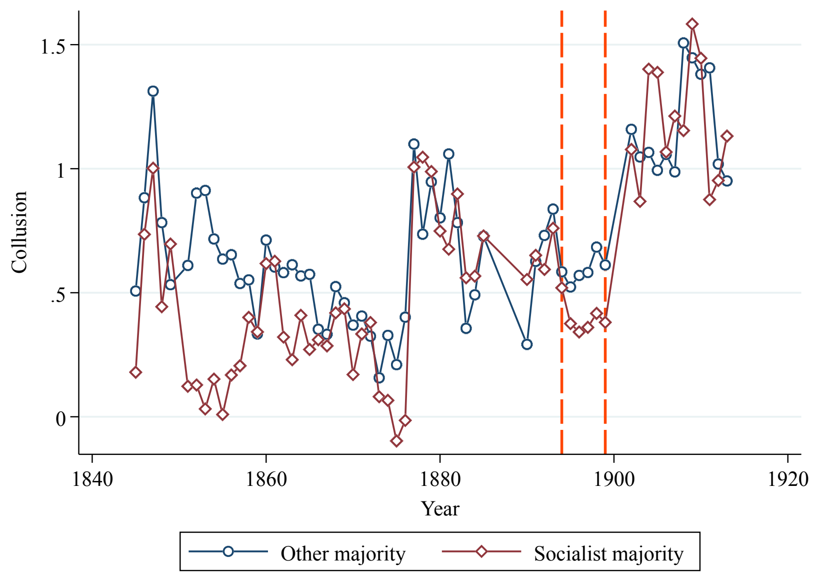
[XV] An important example is the 1891 encyclical of Pope Leo XIII, *Rerum Novarum* or *Rights and Duties of Capital and Labor*, which had a revolutionary impact on the Belgian Christian party. In this letter, the Catholic leader also expressed his condemnation of what we would now call monopsony: "doubtless, before deciding whether wages axe fair, many things have to be considered; but wealthy owners and all masters of labor should be mindful of this - that to exercise pressure upon the indigent and the destitute for the sake of gain, and to gather one's profit out of the need of another, is condemned by all laws, human and divine" (Leo XIII, 1891).

Figure C.13: **Local election results in the coal communities of Liège and Namur, 1895-1899**

(a) **Evolution of voter shares**



(b) **Market-level median collusion by political majority**



Notes: The upper panel documents the substantial and increasing support of the POB in the communities of our sample. In the lower panel, we differentiate between communities with a socialist or another-party majority based on the results of the 1899 local elections. The two dashed vertical lines represent the 1895 and 1899 elections respectively.

Source: Local election results can be found in the archives of the Belgian ministry of internal affairs. This source was digitized by the *Quetelet Center for Quantitative Historical Research* (Ghent University).

War. Full universal male suffrage was only granted in 1919, allowing the POB to finally play an important role on the national political scene.[XVI] At the same time, however, the cartel era gained further steam, and cartels became increasingly formalized, and were even encouraged by the Belgian government (Vanthemsche, 1983). It remains to be seen how these diverging trends affected market power and collusion on labor and product markets as this period falls beyond the scope of our historical sources. We leave this intriguing question for future research.

[XVI] Uncoincidentially, it was also only in this era that trade unions would become legitimate political institutions as well as recognized partners in the wage bargaining process (see Section 2.3).

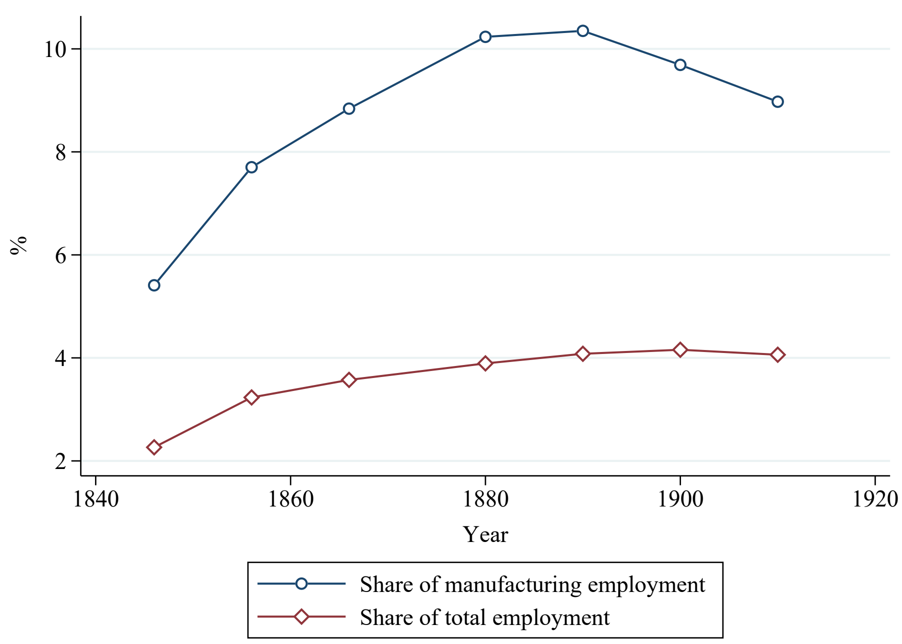
D Additional empirical results and background data

D.1 The Belgian coal industry in the long 19th century

Figure D.1 illustrates the strong importance of coal mining in the Belgian industry throughout the 19th century from an employment perspective. Further disaggregation of the data in Belgian population censuses to the province level indicates that in 1846, about 5% and 4% of male and female workers of the provinces of Liège and Namur, respectively, worked in coal mining. By 1910, this share increased to 10%, while it remained relatively constant in Namur. Overall, these data paint a picture of the coal industry as a prominent employer, both at the national and regional level.

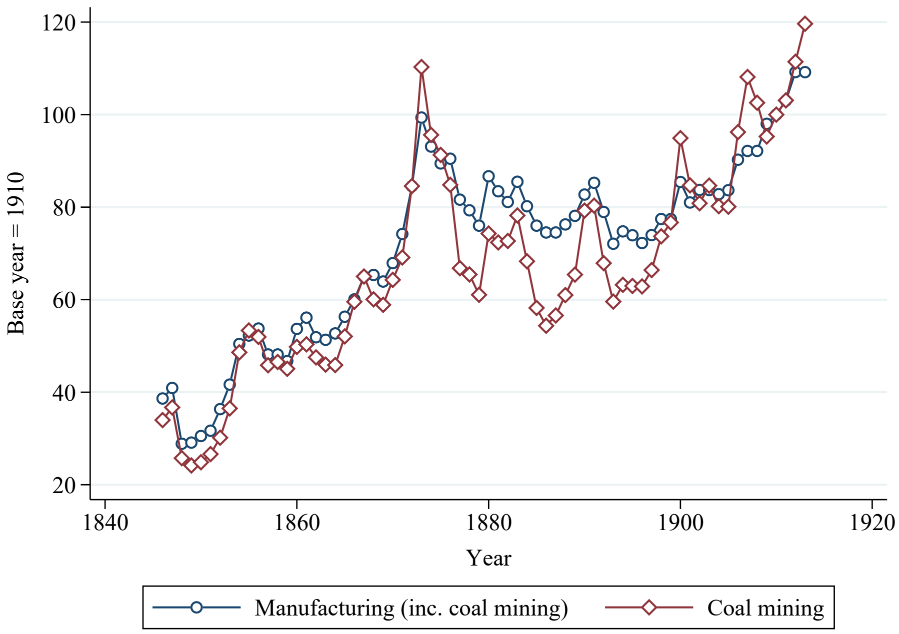
Moreover, Figure D.2 underlines how wage developments in coal mining are indicative of the evolution in the industry overall. These employment shares are based on the industrial censuses of 1846 and 1896, allowing for comparison through the adaptation by Delabastita and Goos (2022). Production shares are based on Statistique de la Belgique (1858) and the *Annales de Mines de Belgique* (Administration des Mines, 1896, 505).

Figure D.1: **Share of coal mining activities in Belgian manufacturing and total employment, 1846-1910**



Source: Coal mining employment is from the published accounts of the *Administration des Mines*, as cited in Gadisseur (1979). Manufacturing and total employment are based on Buyst (forthcoming).

Figure D.2: **Real wage index in Belgian coal mining and the entire Belgian manufacturing and mining sector, 1846-1913**



Source: Coal mining wages are from the published accounts of the *Administration des Mines*, as cited in Scholliers (1995). Manufacturing wages and the Consumer Price Index are based on Segers (2003).

Figure D.3: **Share of coal mining employees involved in Belgian strikes, 1896-1910**

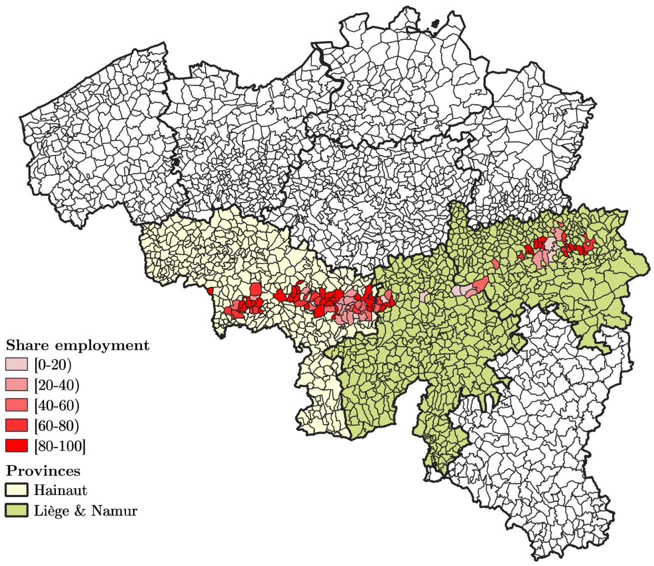
(a) Number of strikes

(b) Number of strikers involved

Notes: The registration of strike action might be biased towards the coal industry due to the high government supervision of this sector. However, the lack of success from the perspective of the employees indicates that there were rents to be fought over and that employers had a particularly strong bargaining position in the decade before the First World War.

Source: Data are adapted from Office du Travail (1903, 1907, 1911).

Figure D.4: **Map of share of coal employment of total industrial manual employment, 1896**



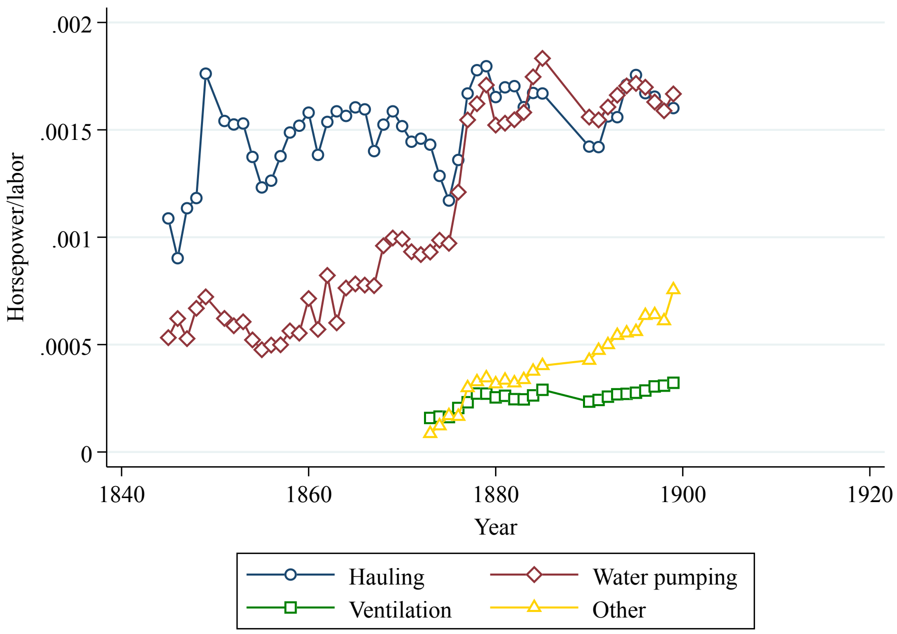
Notes: Historical community borders of 1890.

Source: Data are adapted from the industrial census of 1896 (Office du Travail, 1896a, 1896b). This source was digitized by the *Quetelet Center for Quantitative Historical Research* (Ghent University).

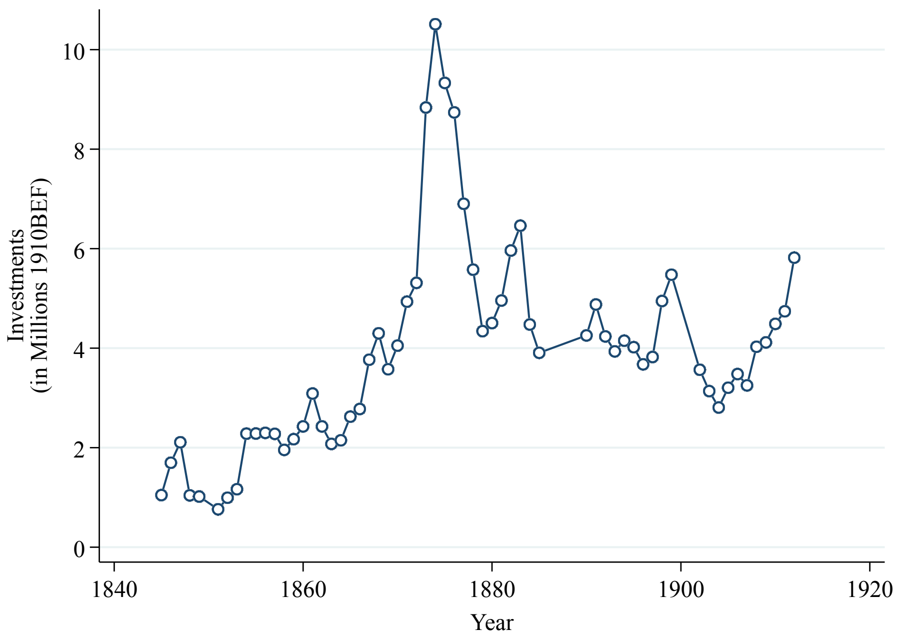
D.2 The Liège and Namur-based coal industry in the long 19th century

Figure D.5: **Mechanization in Liège- and Namur-based coal mining**

(a) **Horsepower per worker-day, by technology, of Liège and Namur coal firms, 1845-1900**



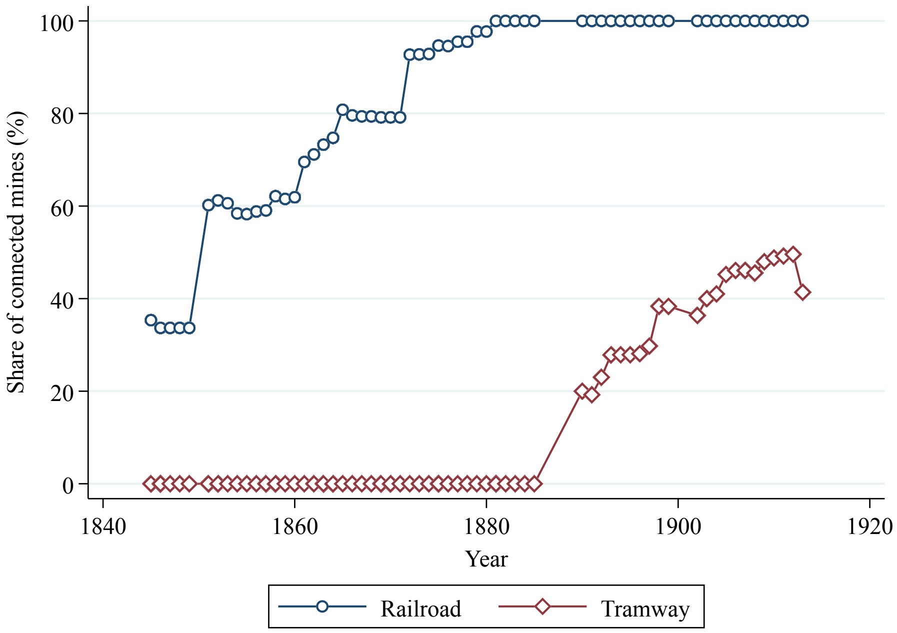
(b) **Total investment by the Liège and Namur coal firms, 1845-1913**



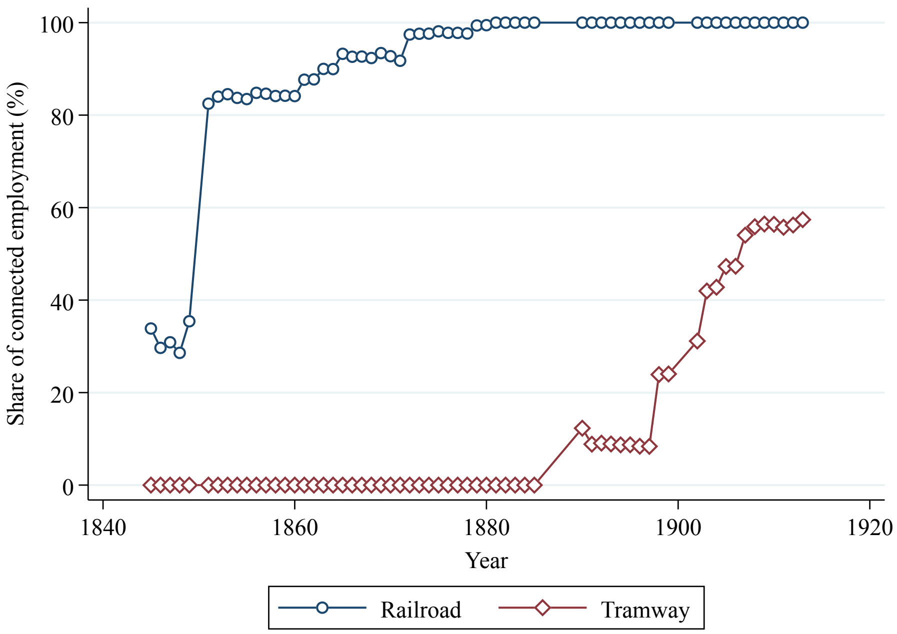
Notes: Figure (a) plots the evolution of horsepower per worker-day for the four technology classes in our dataset. Figure (b) plots the evolution of total capital investment of coal mines in the sample.

Figure D.6: **Expansion of the railroad and tramway networks, connection to Liège and Namur mines, 1845-1913**

(a) **Share of connected mines (firms)**



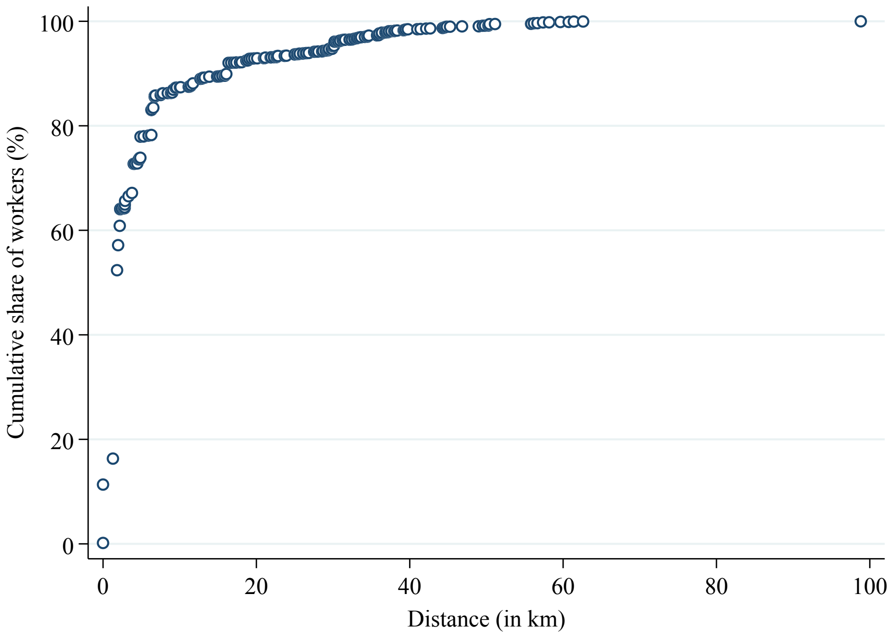
(b) **Share of connected employment**



Notes: Figure (a) plots the evolution of the share of mines that are connected to the railroad and tramway networks. Figure (b) does the same, but weights by employment shares.

Source: Authors' database. Opening dates of Belgian train stations are provided by the *Quetelet Center for Quantitative Historical Research* (Ghent University). For more information, see Section B.2.

Figure D.7: **Commuting distances in 1905**



Notes: This figure plots the cumulative commuting distances of miners for a 1911 survey of two large coal mines.
Source: Own calculations based on the survey by Mahaim (1911) at the Liège-based firms *Ougrée-Marihaye* and *Espérance-Bonne-Fortune*.

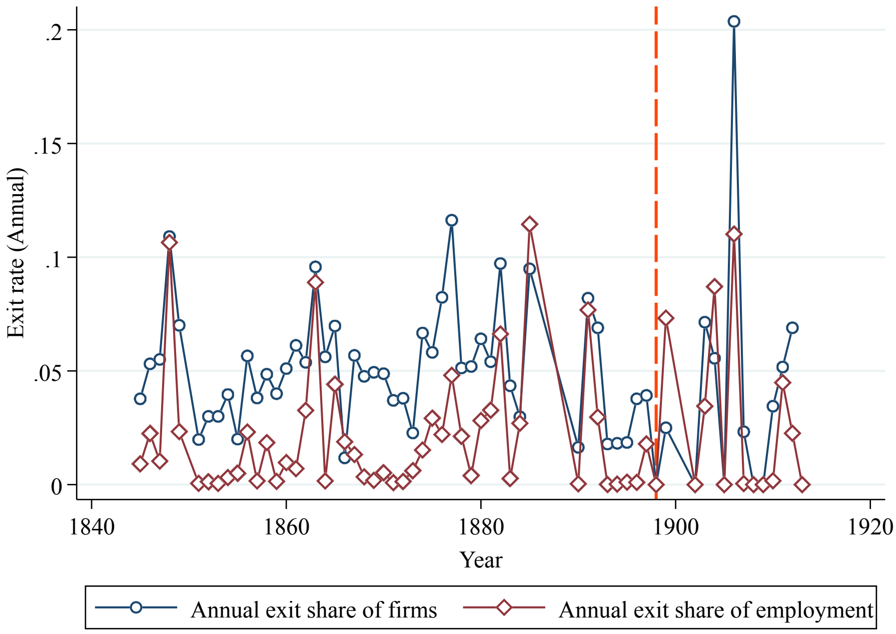
D.3 Endogenous exit

The model in the main text is mainly concerned with the intensive margin effects of collusion. However, a breakdown of the cartel could have resulted 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. We start by noting that exit rates did not trend significantly downward after the entry of the cartel. Figure D.8a shows annual exit rates as a share of the number of firms and as a share of industry employment. Figure D.8b does the same but for four-year-long time blocks. The exit rate remained relatively stable in the long run at around 5% of firms and 2-3% of total employment per year. There seems to be no decline in the exit rates after the entry of the cartel in 1898.

However, the time series in exit rates does not fully inform us about the counterfactual exit probabilities in the absence of the cartel. To infer counterfactual exit rates, we need to know fixed costs and variable profits in the absence of the cartel.

Figure D.8: **Exit rates in Namur- and Liège-based coal mining, 1845-1913**

(a) **Annual exit rates**



(b) **Four-year window exit rates**

Notes: Panel (a) plots annual exit rates, both in terms of the number of firms and as a share of total employment. Panel (b) does the same, but averages exit over four-year time windows. The dashed vertical line represents the start of the coal cartel, the *Syndicat de Charbonnages Liégeois*.

Methodology

We compute bounds on fixed costs similarly to the methodology of Verboven and Yontcheva (2022), which builds on the moment inequalities literature (Pakes, 2010; Eizenberg, 2014; Berry, Eizenberg, & Waldfogel, 2016). Using the equilibrium expressions from Section 4.2, we compute variable profits $V(N_{it}, .)$ in each market as a function of the number of firms N_{it}:

$$V(N_{it}, .) = P(N_{it}, .)Q(P(N_{it}, .), .) - W^l(N_{it}, .)L(W^l(N_{it}, .), .) - W^m M(P(N_{it}, .), .)$$

We infer fixed costs bounds using a revealed preferences approach (Bresnahan & Reiss, 1991; Berry et al., 2016). Fixed costs should be lower than variable profits under the observed market structure (otherwise, firms would exit the market) but higher than variable profits under market structure with one additional firm (otherwise, firms would enter the market):

$$\begin{cases} V(N_{it}, .) & \geq F_{it} N_{it} \\ V(N_{it}+1, .) & \leq F_{it}(N_{it}+1) \end{cases} \tag{D.1}$$

Results

Panel A of Table D.1 reports the estimated fixed cost bounds as specified in Equation (D.1) in the model with exogenous coal prices (first column) and endogenous coal prices (second column). The estimates are the average of these fixed costs bounds taken across all markets and years. We obtain narrow median fixed costs bounds of 74,000 to 80,000 BEF for the exogenous price model and of 71,000 to 76,000 BEF for the endogenous price model. In comparison, the median capital investment (whenever larger than zero) in the accounting data is 21,654 BEF, and the average capital investment is 58,974 BEF.

To infer how many firms would exit the market in the counterfactual scenarios of Cournot competition and pre-1898 conduct, we estimate fixed costs as the midpoint in between the lower and upper bounds for every market. In Figure D.9, we compare these estimated fixed costs against the observed capital investment in the accounting data by plotting the logarithms of both variables against each other. The correlation between the estimated and observed fixed costs is 0.822 for the exogenous price model and 0.849 for the endogenous price model.

Table D.1: **Endogenous exit**

Panel A: Fixed costs	Average fixed cost (million BEF)	
	Exg. price	End. price
Upper bound	0.080	0.076
Lower bound	0.074	0.071
Panel B: Exit change - exogenous price	Change from cartel to:	
	Cournot	Pre-1898 conduct
Relative exit change	1.842	1.041
Panel C: Exit change - endogenous price	Change from cartel to:	
	Cournot	Pre-1898 conduct
Relative exit change	1.421	0.122

Notes: Panel A contains the bounds for average fixed costs for both the exogenous and endogenous coal prices model. Panels B-C contain the relative change in the exit rate when moving from full collusion to either Cournot competition or to the estimated level of conduct before 1898.

The first column in Panel B of Table D.1 reports the average change in the firm exit rate when moving from the cartel to Cournot equilibrium, using the model that assumes exogenous coal prices. When moving from the cartel equilibrium to Cournot labor market competition, the exit rate would almost triple (an increase of 184%). The reason for this is it that a breakdown of the cartel into Cournot competition would result in drastically lowered wage markdowns, to the extent that fixed costs would no longer be recovered by a part of the firms. Given that these firms are assumed to exit as long as their total profits fall below zero, the exit rate increases sharply in the Cournot counterfactual. The second column in Panel B shows the change in the average exit rate when moving from the cartel to pre-1898 conduct. In this case, the exit rate would double, rather than triple. The reason for this is that markdowns were higher under the observed degree of labor market conduct prior to 1898 than under Cournot competition.

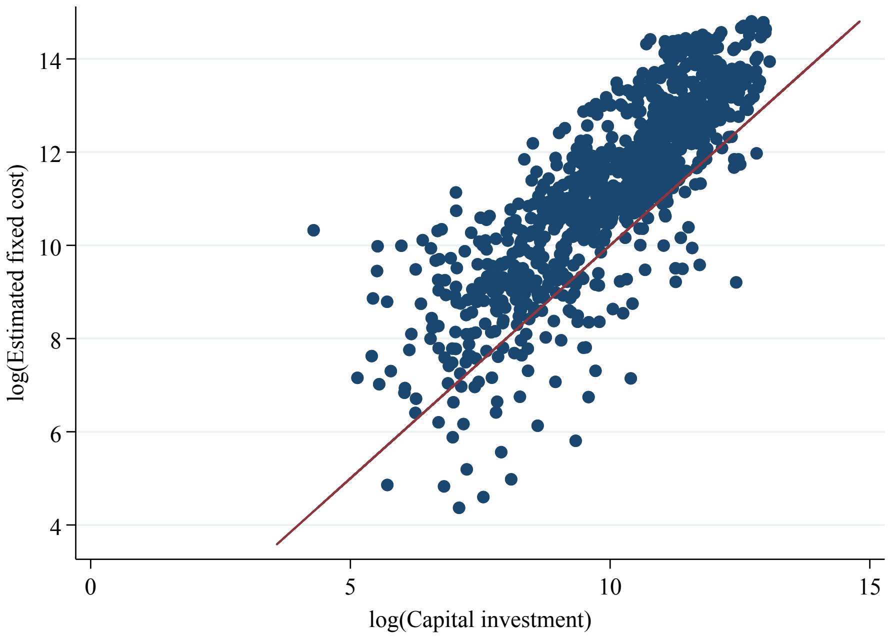
The large change in the exit rate for both the Cournot and pre-1898 conduct counterfactuals is logical: under the exogenous price model, the only source of profits is the wage markdown. Given that labor markets are not very concentrated, Cournot markdowns are low. Hence, variable profits fall considerably when moving to either Cournot or pre-cartel conduct as this considerably reduces firm profits. However, the fact that observed exit rates prior to 1898 are low contradicts this counterfactual prediction, and suggests that it is not crucial to take into account endogenous exit in the counterfactual analysis.

Panel C of Table D.1 reports the exit rate changes in the endogenous price model. When moving to the Cournot equilibrium, exit rates still increase considerably by 142%. However, moving to the pre-1898 labor market conduct has much more muted effects on exit: an increase of 12.2% on average. Given that the observed exit rate was 4.34% after the cartel introduction, this counterfactual implies that not introducing the cartel in 1898 would have increased exit to 4.87%.

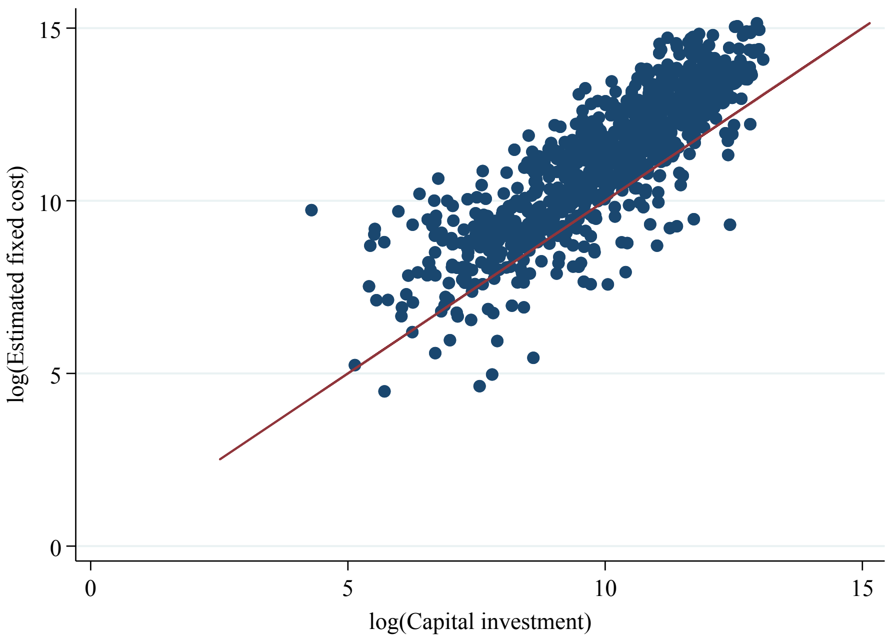
In sum, we find exit rates would be higher in the absence of the cartel, although the magnitude of this effect is relatively small under the assumption that firms had some market power downstream. However, given that the baseline exit rate was small, the additional exit in the absence of the cartel would have been limited. Nevertheless, we think that endogenous entry and exit are important when thinking about the welfare effects of labor (and product) market power and should be taken into account when designing merger and antitrust policies.

Figure D.9: **Fixed costs estimates**

(a) **Exogenous price model**



(b) **Endogenous price model**



Notes: This figure plots the log of estimated fixed costs against the log of observed capital investment in (a) the exogenous coal price model, and (b) the endogenous coal price model. The solid lines represent the 45°-line.

D.4 Markups and the cartel

In Table D.2, we estimate how coal price markups changed in response to the coal cartel. We rely on a difference-in-differences setup, comparing cartel members to non-members before and after the cartel introduction. As could be expected, we find that markups increase among the cartel participants after the cartel started. When not including mine fixed effects in the difference-in-differences equation, markups increased on average by 23% among the cartel firms relatively to the dissenters. When including mine fixed effects, this relative change increases to 30%.

Table D.2: **Markup responses to the cartel**

	log(Markup)		log(Markup)	
	Est.	S.E.	Est.	S.E.
1(Year>1897)*1(Cartel member)	0.230	0.075	0.300	0.094
Mine FE	No		Yes	
R-squared	.023		.239	
Observations	4705		4705	

Notes: This table regresses a difference-in-differences model that compares markup growth between cartel members and non-members before and after the cartel introduction. Block-bootstrapped standard errors are computed using 200 iterations.

D.5 Coal demand estimates

We estimate the coal demand function in Equation (18) at the municipality-year level and include municipality fixed effects. We rely on the log mining TFP, as estimated in our production model, as an instrumental variable. Mining productivity affects coal supply, but it does not affect consumer demand for coal, conditional on the coal price. We estimate Equation (18) in logs at the municipality-year level using 2sls with log TFP as the instrument for the log coal quantity. The results are in Table D.3. As soon as we instrument, we obtain a negative demand slope with an inverse elasticity of -0.383.

Table D.3: **Coal demand**

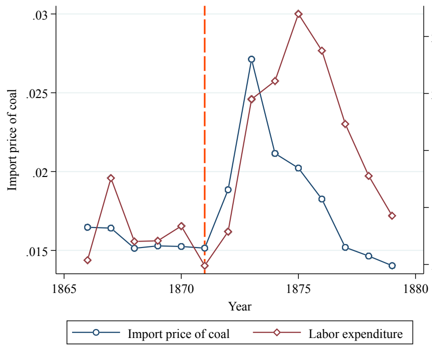
	log(Price)		log(Price)	
	Est.	S.E.	Est.	S.E.
log(Output)	0.073	0.004	-0.383	0.116
Method	OLS		IV	
First-stage F-statistic			22.7	
Observations	1913		1913	

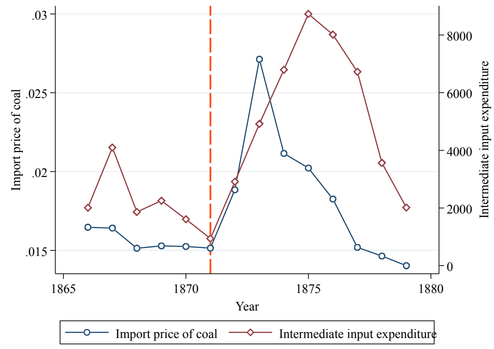
Notes: The table reports the OLS and 2SLS estimates of the coal demand function, with robust standard errors. The IV model relies on log mining TFP as a cost shifter. A linear time trend is controlled for in both specifications.

D.6 Other results

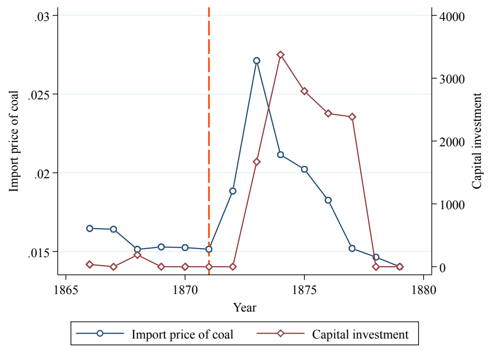
Figure D.10: **Impulse-response function of input usage**

(a) **Labor expenditure** (b) **Intermediate input expenditure**





(c) **Capital investment**



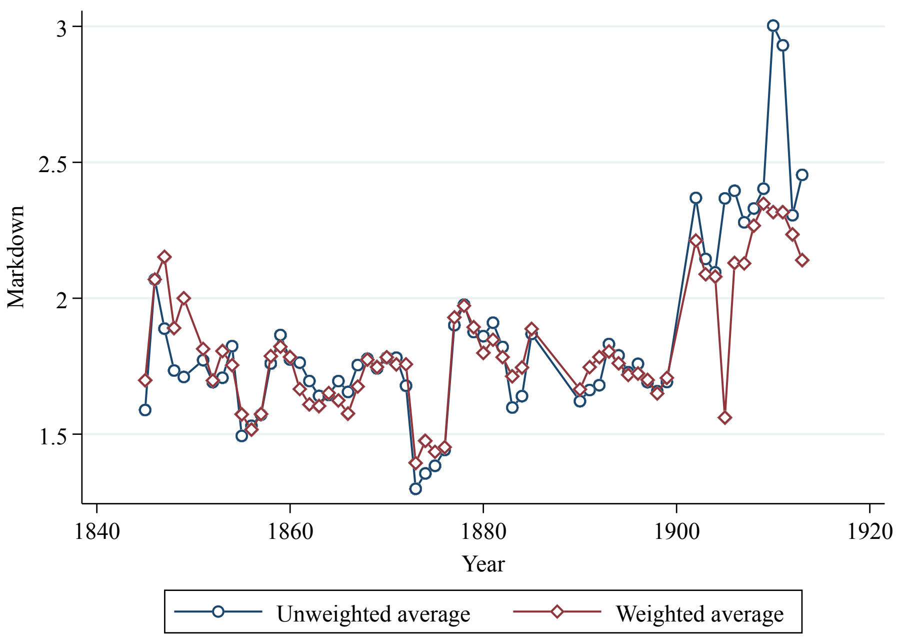
Notes: These figures plot the evolution of labor, intermediate input, and capital expenditure after the 1871 international coal price shock. The dashed vertical lines indicate the coal demand shock. The import price of coal is also plotted.

Table D.4: **Agricultural wages and mining labor supply**

	Δ log(Coal mining employment)		Δ log(Coal mining employment)	
	Est.	S.E.	Est.	S.E.
Δ log(Agricultural wage)	-0.475	0.125	-0.839	0.165
Δ log(Industrial wage)	.	.	0.503	0.183
R-squared	.154		.249	
Observations	58		58	

Notes: This table reports the estimates of a regression of the yearly change in the log total number of workers in the Liège and Namur coal basin on the yearly change in log agricultural wages in Belgium, between 1845 and 1913. Robust standard errors are included.

Figure D.11: **Markdown reallocation**



Notes: This graph compares the evolution of the unweighted and weighted average (by employment) of the wage markdown in Liège and Namur coal mines from 1845-1913.