Colluding Against Workers: Evidence from Belgium, 1845-1913

Vincent Delabastita* Michael Rubens†
KU Leuven KU Leuven

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Abstract

Are wage markdowns due to collusion between employers, or to other sources of labor market power? We propose an empirical framework to identify collusion on labor markets using production, cost, and wage data. We use it to study collusive wage-setting behavior by 220 coal firms in Belgium from 1845-1913. We find evidence for substantial collusion against workers, which is consistent with anecdotal evidence. This collusion was stable throughout Belgium's Industrial Revolution from 1845 to 1900, but increased sharply after the turn of the century. This surge in collusion coincided with the emergence of coal cartels.

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*Email: vincent.delabastita@kuleuven.be
†Email: michael.rubens@outlook.com
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1 Introduction

There are growing concerns about increasing levels of labor market power by firms.[1] A key open question is whether such wage-setting power is the result of collusion between employers on the labor market, or from other sources of labor market power, such as labor market frictions, concentration, or employer differentiation.[2] Several high-profile cases against high-tech firms, fast-food chains and oil companies over the past decade suggest that anti-competitive practices, such as anti-poaching and wage-fixing agreements, prevale in labor markets today (Krueger & Ashenfelter, 2018, Naidu, Posner, & Weyl, 2018, 597-598). Moreover, there is ample anecdotal evidence of employer collusion against workers throughout economic history, through labor market institutions such as guilds and employers' associations. Despite all this evidence, collusive wage-setting behavior by employers is mostly absent from current empirical research on oligopsony power.[3] Knowing the sources of 'monopsony' or 'oligopsony' power on labor markets is crucial when designing policies to constrain such market power.[4] For instance, antitrust policy against collusive practices has a key role in addressing oligopsony power if it is due to employer collusion, but not if it is mainly due to firms exploiting labor market frictions.

In this paper, we propose a novel empirical approach to detect and quantify employer collusion on labor markets using firm-level production, cost, and wage data. We apply this method to study the level, evolution, and drivers of wage collusion between 227 Belgian coal firms between 1845 and 1913. These 69 years of data cover most of the industrialization of Belgium, the first country on the Continent to participate in the Industrial Revolution. A common problem when empirically studying collusion in current-day settings, is that it is illegal in most countries, and hence hard to observe. Our approach, which builds on methods from empirical industrial organization, has the benefit that it does not require observing collusive behavior or structures such as

[1]See, for instance, Krueger (2018) and surveys in Manning (2021) and Sokolova and Sorensen (2021).

[2]Recent examples include Caldwell and Harmon (2019) for oligopsony power due to search frictions, Card, Cardoso, Heining, and Kline (2018) for heterogeneous worker tastes over firm-specific (dis)amenities, and Schubert, Stansbury, and Taska (2021) for labor market concentration.

[3]In his well-known literature review, Manning (2011, 979) already considered the potential role of collusion on labor markets an "open question". We find that little has changed since then.

[4]For the remainder of the paper, we use the terms 'oligopsony' rather than 'monopsony', because actual monopsonies are scarce.

cartels. Moreover, given that collusion by firms on labor and product markets was tolerated by the Belgian government during the 19$^{\text{th}}$ century, we observe information on collusive wage-setting by firms through employers' associations, and use it to validate our results. In contrast, collusion by workers in the form of trade unions was long illegal, and the right to strike was heavily constrained.

The historical setting of Belgian coal mining offers an interesting setting to study employer collusion for three additional reasons. First, the archives of the Belgian *Administration des Mines* provide us with a wealth of fine-grained production, employment, and wage data at the firm level, covering an unusually long period that includes a part of the first and the entire second Industrial Revolution.[5] This gives us a unique view of how labor market power and collusion evolves as countries industrialize and develop. Second, the coal industry has limited scope for product differentiation, and the dimensions of coal differentiation are observed, and features single-product firms. This facilitates the estimation of the model, even if it can be extended to settings with differentiated goods and multi-product firms. In spite of this 'special' feature on the goods market side, we argue that our findings on employer collusion during the Industrial Revolution have some external validity beyond the coal mining industry. Belgian coal mines were usually not geographically isolated in 'mining towns', but located within commuting distance from large industrial cities. The local labor market conditions were hence very similar for coal firms and manufacturing firms, and if the former could collude against their workers, there are many reasons to believe the latter did so as well.[6] Finally, the coal industry is interesting in its own right from a historical perspective due to its size and central role in the Industrial Revolution (Fernihough & O'Rourke, 2021). In the last two decades of the 19$^{\text{th}}$ century, coal mines employed 10% of industrial workers in Belgium, more than any other extractive or manufacturing industry (Buyst, forthcoming).

The key empirical challenge when studying collusive behavior by firms, be it on product or factor markets, is that both marginal costs of production and competitive

[5]The *Administration*, the official engineering institute tasked to supervise the state's mining concessions, has its roots in the French period. Due to these roots, their close statistical, firm-level monitoring was an anomaly in Belgium's prominent *laissez-faire* policy environment, and exceptionally allows us to identify labor market conduct and its drivers in a setting where limited institutional checks and balances were in place.

[6]We have anecdotal information that this was the case in, for instance, the steel manufacturing industry in Belgium.

conduct are unobserved. The usual approach to study collusion in empirical industrial organization is to rely on rotations of the goods demand curve (Bresnahan, 1982). We follow a different approach that relies on combining a model of production to infer marginal costs, as in De Loecker and Warzynski (2012), with a model of labor supply in the tradition of Berry (1994) and Card et al. (2018).[7] Our identification strategy follows two steps. First, we identify the *wage markdown*, the wedge between worker wages and their marginal product, by estimating the coal mining production function and comparing first order cost-minimization conditions between labor and intermediate inputs from the production-cost approach, as in Morlacco (2017).[8] This allows us to separately identify the product price *markup*, the wedge between marginal costs and goods prices, from the wage markdown under any model of competitive conduct. Second, we need to know how much of this markdown wedge is due to collusion between firms, or to other sources of labor market power. We identify the wage markdown under the assumption that there is no collusion between firms on the labor market by using a discrete-choice model in the spirit of Berry (1994) for labor supply, as in Card et al. (2018) and Azar, Berry, and Marinescu (2019). This labor supply model, which can be estimated using data on wages, labor market shares, and labor demand shifters, allows to identify the optimal wage markdown in the counterfactual world without employer collusion. Finally, comparing the 'conduct-free' and 'non-collusive' markdowns gives a measure for the degree of employer collusion in the market. The main caveat to our approach is that the discrete choice models of labor supply also assume a frictionless labor market, and assume that firms only derive market power from either labor market concentration or firm differentiation and non-wage 'amenities'. We argue that this fits the setting of 19th century Belgian labor market well. Our approach could be extended to other settings in which labor market frictions, such as hiring and firing costs or worker-side switching costs, are of first-order importance. The non-collusive benchmark model to which the 'conduct-free' markdown is compared should then allow

[7] A similar approach was taken by De Loecker and Scott (2016) on the product market side, without explicitly focusing on collusion, but making a more general point on conduct identification instead.

[8] This requires the assumption that intermediate input markets are perfectly competitive. Other approaches that use the same normalization are Mertens (2020), and Brooks, Kaboski, Li, and Qian (2021).

for labor market frictions.[9]

Our findings summarize as follows. First, we find evidence for a substantial degree of employer collusion throughout the entire period of 1845-1913. Throughout the 19$^{\text{th}}$ century, the wage markdown was around 50% higher in reality than what it would be in the absence of collusion between employers, and this difference was relatively stable. This is, at first sight, surprising: we study an unconcentrated labor market with low labor market shares, frequent entry and exit, and a mobile labor force due to the well-developed Belgian railroad network, and would hence suspect little scope for collusion. However, a majority of coal firm executives met on a weekly basis to discuss wage-setting during meetings of so-called 'employers' associations'. We find that wage collusion among the members of these associations was, indeed, around 20% higher compared to non-member firms. Furthermore, we find that wage collusion anti-cyclical, which is in line with collusion theory (Rotemberg & Saloner, 1986). Second, we find evidence of an important rise in employer collusion starting around 1900: the markdown became more than twice as high than the non-collusive markdown after 1900. The timing of this spike in employer collusion coincides with the emergence of coal cartels on the Belgian and European coal markets in the late 1890s, which fits into the broader emergence of cartels across many industries during that time period. Downstream cartels lead to reduced output, and hence also to reduced labor demand, which reinforces collusive behavior on labor markets as well.

Our work connects to three broad strands of literature. First, we contribute to a vast literature on imperfectly competitive labor markets. As surveyed in Manning (2021), this literature is split into two traditions, depending on the source of wage-setting power by firms. In the equilibrium search models in the tradition of Burdett and Mortensen (1998), firms have some wage-setting power due to search frictions.[10] On the other hand, in differentiated firms models such as Card et al. (2018); Azar et al. (2019); Lamadon, Mogstad, and Setzler (forthcoming); Berger, Herkenhoff, and Mongey (2019), employers obtain some wage-setting power from the fact that they

[9]See Manning (2021) for a general discussion. There exist discrete choice demand models with switching costs, see Honka (2014) for an example and (Farrell & Klemperer, 2007) for a more general discussion. Adding labor market frictions to the model would also require modifying the identifying restrictions for the production function, markdowns, and markups.

[10]Examples include Postel-Vinay and Robin (2002) and Cahuc, Postel-Vinay, and Robin (2006), among many others.

are not perfect substitutes from the worker's point of view. Both these bodies of literatures assume, however, that firms set wages non-cooperatively. In contrast, we allow for collusive wage-setting by employers and extend the latter class of models with differentiated employers to allow for cooperative wage-setting, and quantify the degree of employer collusion.

Second, we build on a long literature of studying collusion in the industrial organization literature. Most of the empirical literature on collusion follows a 'demand-side' approach in the tradition of Bresnahan (1982, 1987). As was mentioned earlier, the key challenge in these models is that both marginal costs and conduct are usually both latent. Possible approaches are to identify shifts in collusion, rather than its level, as in Ciliberto and Williams (2014), to rely on in-sample variation in ownership, as in Miller and Weinberg (2017), or to find instruments that are orthogonal to affect only marginal costs but not conduct, or vice-versa (C. Michel & Weiergraeber, 2018). 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. De Loecker and Scott (2016) compares the demand- and cost-side identification of markups for the beer industry, and suggests the combination of these approaches to identify conduct. We follow up on this suggestion, but in the context of wage collusion in oligopsony, rather than product price collusion in oligopoly.[11] Another novelty of this paper is to examine the effects of product market cartels on upstream collusion. We discuss the conditions under which collusion can differ between input and output markets, and provide evidence of how goods market cartels affect labor market competition using observable information on coal cartels in Belgium.

Third, our results present new evidence on the economic history of employer collusion and anti-competitive labor market institutions. Various historical examples of collusive behavior have emerged in the historical literature. Guilds, organizations that characterized craft and mercantile activities in European economies for centuries, were prime culprits: in her seminal overview, Ogilvie (2019, 190-191) finds that labor market manipulation was a widespread practice, and documents more than hundred instances of guilds imposing wage ceilings on its members. Domestic textile production, in which 'putting out' activities remained an invaluable source of income for many until deep in

[11] Rubens (2021) also combines a factor supply model with a production model, but for a different purpose, recovering markups and markdowns in the presence of non-substitutable inputs.

the 19$^{\text{th}}$ century, was traditionally also characterized by collusion between textile firms (Humphries & Schneider, 2019, 152). Moreover, examples of collusion are not limited to pre-industrial forms of labor organization. Throughout the 19$^{\text{th}}$ century, employers increasingly unionized in so-called 'employers' associations', in which employers sought to defend common commercial interests, control their labor force and counter emerging trade unions.[12] A prominent example can be found in British coal mining during the Victorian era, where multiple coal owners' associations actively fixed wages in concert (Church, 1986, 651-674). Finally and relatedly, this tendency of coal firms to unionize translated into a surge of coal cartels after the turn of the century across Continental Europe, providing a likely framework for collusion not only on the product market, but also the labor market (for a concise overview, see Murray & Silvestre, 2020, 679-680). Despite this large body of historical and anecdotal evidence of the importance of employer collusion, there is little quantitative evidence for the level and evolution of this employer collusion throughout the Industrial Revolution, which is where this paper contributes.[13]

The remainder of this paper is structured as follows. Section 2 contains a general model to quantify the degree of collusion in a market by combining a model of production with a model of factor supply and/or goods demand. Section 3 discusses the historical setting of Belgian coal mining during the 19$^{\text{th}}$ and early 20$^{\text{th}}$ century, and presents the data. In Section 4, we estimate the degree of collusion between Belgian mining firms when setting miner wages using the model from section 2. We also investigate some correlations of employer collusion with observable information on employer associations and business cycle fluctuations, to validate our collusion estimates. Finally, in Section 5, we assess the effects of the spread of coal market cartels around 1900 on employer collusion, and investigate the interaction between upstream and downstream collusion. Finally, Section 6 concludes.

[12] Empirical research on the role of employers' organizations is scarce, however. Exceptions with a historical focus can be found in Yarmie (1980) for the U.K. and Vanthemsche (1995) for Belgium. A current-day analysis of employer unions is in (Martins, 2020), who studies how firm performance measures differ between members of such unions and other firms.

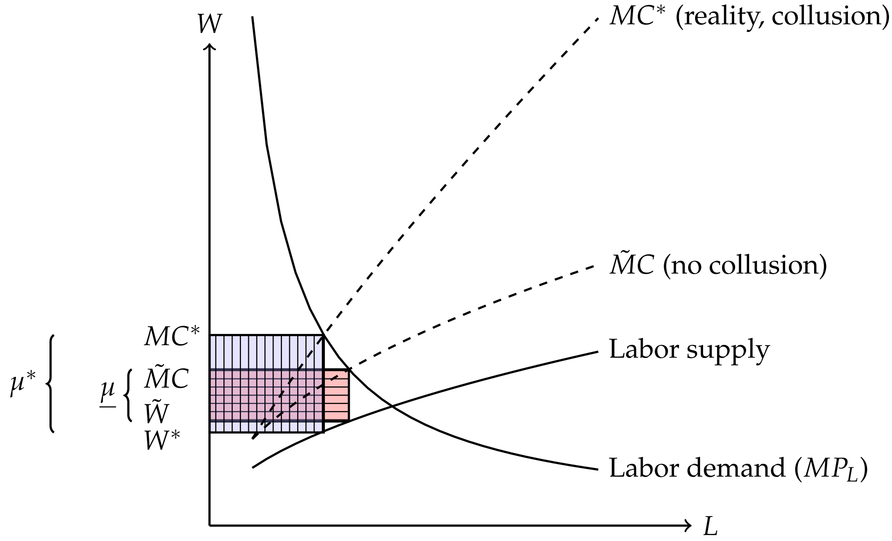
[13] Whereas collusion between employers was usually illegal, there were legal restrictions on striking and unionization. Naidu and Yuchtman (2018) present evidence of substantial firm-specific rents in 19$^{\text{th}}$-century US labor markets, facilitated by legal restrictions on striking efficacy.

2 Identifying conduct with production and cost data

2.1 Intuition

Figure 1 illustrates the key empirical challenge addressed in this paper. Consider a firm that faces an upward-sloping labor supply curve. For expositional purposes only, assume that the goods market is perfectly competitive.[14] The firm sets the profit-maximizing wage W^* at a markdown μ^* below the marginal product of labor, which is equal to the marginal labor cost MC^*. If we would observe this marginal cost, we could calculate the wage markdown by comparing marginal costs to wages. However, in reality, marginal costs are latent and need to be inferred using a model of behavior by firms and their input suppliers.

Figure 1: **Markdowns and employer collusion**



The marginal cost curve will differ depending on whether there is collusion or not. Suppose there is collusion between firms, meaning that firms internalize some of the profits of their competitors. In an oligopsonistic input market, increasing production of a firm leads to higher input prices at that firm (due to an upward-sloping input supply curve), but also to increasing input prices at its competitors. In a collusive model, costs of competitors enter the firm's objective function, and hence affects its marginal cost curve. In contrast to the oligopolistic setting of product markets, higher marginal

[14]Our identification strategy will allow for imperfect competition on both factor and goods markets. Figure F.1 extends to a setting with imperfect factor *and* goods markets.

costs imply higher profits: firms derive profits from the wedge between marginal costs and input prices.

The classical approach to separately identify conduct from marginal costs is to use demand rotations (or in this oligopsonistic setting, supply rotations), as in Bresnahan (1982). We use an alternative approach. Suppose we can estimate actual marginal costs MC^* without making an assumption about collusion, using production and cost data. In order to know what fraction of the markdown μ^* is due to the slope of the input supply curve, and which fraction is due to collusion between employers, we need to compare this actual markdown μ^* to the counterfactual markdown if there would be no collusion between firms, $\underline{\mu}$. This boils down to the markup comparison made in De Loecker and Scott (2016), but using wage markdowns instead of price markups. The ratio of variable profits in the actual, collusive, state of the world compared to a counterfactual world without employer collusion is equal to the fraction of the blue, vertically shaded area over the red, horizontally shaded area. In the next section, Section 2.2, we will formalize this intuition into a model that allows for collusion on both goods and factor markets.

2.2 Markups and markdowns

Environment and notation

Consider a firm f that produces a quantity Q_{ft} of a single good using J variable inputs $V^j_{ft} \in \mathbf{V}_{ft}$ and fixed inputs $\mathbf{K}_{ft}$. The inputs $\mathbf{V}_{ft}$ are 'variable' because they can be flexibly adjusted in any time period, in contrast to the fixed inputs $\mathbf{K}_{ft}$. We assume that all inputs are substitutable.[15] The production function is given by Equation (1), with parametrization $\boldsymbol{\beta}_{ft}$ and a Hicks-neutral productivity shifter ω_{ft}.

$$Q_{ft} = Q(\mathbf{V}_{ft}, \mathbf{K}_{ft}, \boldsymbol{\beta}) \exp(\omega_{ft}) \tag{1}$$

Each variable input $V^j_{ft} \in \mathbf{V}_{ft}$ is purchased at a price $W^j_{ft} \in \mathbf{W}_{ft}$, and output is

[15]Markup and markdown identification in the presence of non-substitutable inputs is discussed in Rubens (2021).

sold at a price P_{ft}. Annual variable profits, which are denoted Π_{ft}, are equal to:

$$\Pi_{ft} \equiv P_{ft}Q_{ft} - \mathbf{W}_{ft}\mathbf{V}_{ft}$$

Each firm faces a supply curve for input V^j with elasticity $(\psi^j_{fft} - 1)$, which can vary over time. This quantifies the extent to which input prices change when input usage changes, and hence the degree of wage-setting power of each firm in time. If the price of input V would be exogenous, then $\psi^j_{fft} - 1 = 0$.

$$\frac{\partial W^j_{ft}}{\partial V^j_{ft}} \frac{V^j_{ft}}{W^j_{ft}} \equiv \psi^j_{fft} - 1$$

When firms change their input usage, this can affect wages at the other firms in the same labor market. This is measured by the cross-elasticity between firms g and f, which is $\psi^j_{fgt} \equiv \frac{\partial W^j_{gt}}{\partial V^j_{ft}} \frac{V^j_{ft}}{W^j_{gt}}$.

We also allow for price-setting power on the goods market: when a firm adjusts its output, the price P_{ft} can endogenously change. Hence, each firm faces an own-price demand elasticity $\eta_{fft} \equiv \frac{\partial P_{ft}}{\partial Q_{ft}} \frac{Q_{ft}}{P_{ft}}$ and a cross-price elasticity $\eta_{fgt} \equiv \frac{\partial P_{gt}}{\partial Q_{ft}} \frac{Q_{gt}}{P_{ft}}$, which can both be zero if product prices are exogenous to each individual firm.

Behavior

Each market contains a set of firms $\mathcal{F}_t$. The firm's objective function is given by Equation (2): a firm f assigns weights γ_{fgt} to the sales of each competitor $g \in \mathcal{F}_t \setminus \{f\}$, and weights λ_{fgt} to the costs of each competitor, with $0 < \gamma_{fgt} < 1$ and $0 < \lambda_{fgt} < 1$. If firms f and g are perfectly colluding on factor markets (when choosing input quantities that minimize joint costs), then $\lambda_{fgt} = 1$, if they do not cooperate then $\lambda_{fgt} = 0$. Similarly, $\gamma_{fgt} = 1$ implies perfect collusion downstream (cooperatively choosing output to maximize joint profits), and $\gamma_{fgt} = 0$ no collusion downstream.

$$\max_{\mathbf{V}_{ft}} \left(\Pi_{ft} + \sum_{g \in \mathcal{F}_t \setminus \{f\}} \left[\gamma_{fgt} P_{gt} Q_{gt} - \lambda_{fgt} (\mathbf{W}_{gt} \mathbf{V}_{gt}) \right] \right) \tag{2}$$

The usual model assumes that firms place a weight on the entire profits of their competitors, meaning that $\lambda_{fgt} = \gamma_{fgt}$. However, we allow for different weights on the sales and costs of the competitors to allow for a different degree of firm collusion on factor and product markets. Different collusion downstream and upstream is possible as soon as there is more than one input, and at least one input of which the market is competitive. Firms can, for instance, collude downstream by jointly lowering output without lowering labor, by substituting from intermediate inputs towards labor. This way, they can collude downstream, but still compete against each other on factor markets. If there is only one input, or if inputs are non-substitutable, output cannot be changed without changing each input, and then it must be that there is an equal degree of collusion upstream and downstream: $\lambda_{fgt} = \gamma_{fgt}$.

Markup and markdown expressions

The output elasticity of a variable input j is denoted $\theta^j_{ft} \equiv \frac{\partial Q_{ft}}{\partial V^j_{ft}} \frac{V^j_{ft}}{Q_{ft}}$. Deriving the first order condition for labor and materials from Equation (2) results in the following system of J equations, one for every variable input j:

$$\frac{\sum_{e \in \mathcal{F}_t} \lambda_{fgt} \psi_{fgt} \frac{W^j_g V^j_g}{W^j_f V^j_f} + 1}{\sum_{g \in \mathcal{F}_t} \gamma_{fgt} \eta_{fgt} \frac{P_g Q_g}{P_f Q_f} + 1} = \frac{\theta^j_{ft}}{\frac{W^j_{ft} V^j_{ft}}{P_{ft} Q_{ft}}} \tag{3a}$$

Assume there exists at least one variable input j^* for all firms are price-takers on the input market, meaning that $\psi^{j^*}_{fg} = 0 \quad \forall f, g$. Writing out Equation (3a) for that input gives the expression for the price *markup* μ^q_{ft}, Equation (3b). This is the degree to which the goods price exceeds its marginal cost, with the right-hand side being equal to the expression from De Loecker and Warzynski (2012).

$$\mu^q_{ft} \equiv (\sum_{e \in \mathcal{F}_t} \gamma_{fgt} \eta_{fgt} \frac{P_{gt} Q_{gt}}{P_{ft} Q_{ft}} + 1)^{-1} = \frac{\theta^{j^*}_{ft}}{\frac{W^{j^*}_{ft} V^{j^*}_{ft}}{P_{ft} Q_{ft}}} \tag{3b}$$

Substituting (3b) into (3a) gives Equation (4), which expresses the input price *markdown* μ^j_{ft}.[16] The right-hand side is the input price markdown, which is identified by comparing the relative wedges between the marginal products of the variable input and its price to the wedge between marginal product and price of the input that for

[16]The same normalization was used in Morlacco (2017), in a non-collusive setting.

which the firm is a price-taker:

$$\mu^j_{ft} \equiv \sum_{c \in \mathcal{F}_t} \lambda_{fgt} \psi_{fgt} \frac{W^j_{gt} V^j_{gt}}{W^j_{ft} V^j_{ft}} + 1 = \frac{\theta^j_{ft} W^{j^*}_{ft} V^{j^*}_{ft}}{\theta^{j^*}_{ft} W^j_{ft} V^j_{ft}} \tag{4}$$

2.3 Employer collusion

Factor market collusion

The right hand-side of Equation (4) is identified if the production function coefficients are identified. In order to know the left-hand side, we need to know (i) the own- and cross-input price elasticities ψ_{fgt} for all firms, and (ii) the collusion weights matrix Λ_t. The former can be obtained using structural production function estimation. For the latter, we can make assumptions regarding the level of collusion, allowing us to calculate Equation (4).

Consider the case in which firms do not collude on their input markets, meaning that Λ_{ft} is the identity matrix: $\lambda_{fgt} = 0$ if $f \neq g$, and $\lambda_{fft} = 1 \quad \forall f$. The left-hand side of Equation (4) then simplifies to ψ^j_{fft}: the markdown of input j is equal to its input supply elasticity: $\mu^j_{ft} = \psi^j_{fft}$. This is a lower bound to the markdown, and we denote this lower bound as $\underline{\mu^j_{ft}} = \psi^j_{fft}$.

The markdown μ^j_{ft}, which can be calculated using the right-hand side of Equation (4) will lie somewhere above the non-collusive lower bound $\underline{\mu^j_{ft}}$. We express the degree of collusion exerted by firm f as the ratio between the actual level of markdown and this lower-bound estimate: $\mu^j_{ft}/\underline{\mu^j_{ft}}$.

Collusion downstream

The entire discussion until now abstracted from collusion downstream: we do not need to know the demand parameters η_{fgt} or degree of collusion downstream Γ_{ft} in order to quantify collusion on input markets, because all the expressions are normalized with respect to the goods price markup μ^q_{ft}. If we would know the demand parameters η_{fgt}, we could additionally quantify the degree of collusion downstream, and test whether there is a different degree of collusion on goods and factor markets. We could also test other conduct assumptions by comparing the cost-side and input supply-model markdowns, such as whether firms are differentiated or whether firms set wages simultaneously or consecutively.

2.4 Caveats

There are three important caveats to the analysis above: technological change, employee labor market power, and frictions. As we will argue here, however, the historical setting of our empirical analysis alleviates these concerns.

Labor-saving technological change

First, in order to correctly identify markups and markdowns, it is crucial to identify all heterogeneity in the output elasticity θ_{ft} across firms and over time.[17]. This is especially true for markdowns: any latent variation in θ_{ft} not captured by the model will show up as variation in markdowns, although it is in reality due to technological differences between firms. We rely on detailed technology data to allow for, and test, labor-saving technological change.

Employee market power

Second, the model assumes that input suppliers are price-takers because employees were not allowed to unionize, whereas employer unions were condoned. If workers would be unionized, this could bring us to a bilateral oligopoly setting, and a bilateral oligopoly model with centralized bargaining would be better suited for the analysis.

Labor market frictions

Third, it could be that there are labor market frictions, such as search frictions or switching costs from the point of view of the workers. These are another reason why the actual markdown and the markdown from the frictionless differentiated firms model would differ.[18] We argue, however, that such frictions are not a credible source of oligopsony power in our setting. First, we regress our collusion estimate on observable shifters of search and migration costs and worker switching costs, in the form of the mines' connection to railroad and tramway networks and the abolition of legal constraints on worker mobility. We do not get results that are economically meaningful

[17]See also Demirer (2020) who makes this point for markups

[18]We leave the extension to allow for both frictions and employer collusion to future work.

(for a discussion, see Appendix C.1). This goes against what one should expect if labor market frictions would be of first-order importance because our collusion measure should be correlated with drivers of such frictions in that case. Second, the historical record indicates that search frictions were quite limited in 19$^{\text{th}}$-century Belgium. Labor contracts were of an informal nature, and hiring and firing costs were nonexistent (Van den Eeckhout, 2005). Furthermore, Belgium's expansive transport network meant that transport costs were low, and that the average Belgian worker was mobile (Huberman, 2008). More specific to our context, Belgian coal workers had indeed the reputation to have a high turnover, changing mines "for a penny" (Leboutte, 1988, 47). Historical evidence shows that coal workers were highly mobile: on average, more than half of the Liège-based coal workers changed workplace 10 to 24 times (Leboutte, 1988, 49).[19]

Finally, it is important to emphasize that, even if there are some frictions (such as moving costs for workers), this only affects the level of our collusion estimate. In other words, we can still rely on our estimates to assess changes in collusion with respect to variation which does not affect search frictions.[20]

[19]This claim is based on the micro-level analysis of the so-called *livrets* of Liège-based coal workers. Employees in the coal mining sector typically had to possess a *livret*, a sort of worker's passport, to partake in insurance schemes regarding accidents and pension funds. Theoretically, these could be considered to be a source of labor market friction, as employers could withhold them from their workers. In practice, however, micro-evidence thus shows that this requirement did not stop coal workers from being highly mobile among employers. Furthermore, legal changes such as its general abolition in 1883 do not show as credible sources of variation in our collusion estimates. We refer to Appendix C.1 for more details.

[20]For example, as our results below will indicate, the introduction of cartels affects our measure of collusion. It is, however, plausible to assume that cartels did not affect search frictions such as the cost of transportation.

3 Coal mining in Belgium, 1845-1913

3.1 Historical background

The industrialization of Belgium

Belgium was notably the first country to industrialize on the European Continent.[21] The technological innovations that were already used in Great Britain trickled over to Belgium during the course of the 18th century, fuelled by the willingness of Walloon entrepreneurs to adopt such innovations.[22] The macroeconomic effects of these developments would take hold in the following decades, with industrial production taking off primarily from the middle of the 19th century (Gadisseur, 1979; Pluymers, 1992). In this sense, the 1840s can be regarded as the peak of Belgium's First Industrial Revolution, with the small country becoming an economic powerhouse in the 1850s and 1860s. This trend would only continue in the age of globalization, during which Belgium's impressive trade boom was driven by a a heterogeneous collection of firms, active on the technological frontier of coal-based sectors such as metal and steel production (Huberman, Meissner, & Oosterlinck, 2017).

Coal industry

The coal mining industry became a major industrial employer throughout the 19th century, with its share of employment in manufacturing attaining to over 15% at the turn of the 19th century.[23] This large labor force was distributed among three provinces in Belgium's industrial belt, from east to west being Hainaut, Namur and Liège.[24] Coal mining in Hainaut - Belgium's prime producer of coal - flourished around Mons

[21]This economic success is often attributed to the rich and easily accessible mineral deposits in the southern, Walloon areas of the country, which facilitated the swift adoption of technological advances which were already successfully employed in Great Britain (Allen, 2009, 104). The discussion on the causes of the Belgian Industrial Revolution mirrors the international debate on whether coal was a crucial determinant in industrialization. Recent research has reappraised the crucial role of coal (Fernihough & O'Rourke, 2021).

[22]This can be clearly illustrated by the 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).

[23]Due to this central role of coal in Belgium's economy, the coal worker became emblematic for the wider labor population (Geerkens, Leboutte, & Péters, 2020).

[24]See the map in Figure A7 in Appendix A. 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*.

(the *Borinage*), due to its excellent canal connections to Flanders and France, and Charleroi, where heavy industries based on English techniques would bolster sizeable demand, much like in Liège (Van der Wee, 1996, 68-69). Mines in Namur were typically small-scale, familial enterprises, geared towards local markets. In this paper, we focus on the coal mines in Liège and Namur: together these provinces represented approximately 3 out of 10 coal workers in Belgium, and 20 to 25% of Belgian coal production throughout the 19$^{\text{th}}$ century.[25] There were on average 60 coal firms per year 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%), cokes producers (10%) and non-ferrous metal manufacturers (10%), together accounting for three quarters of sales (De Leener, 1908).

An important change in the competitive environment of the Liège-based coal industry happened on July 1, 1897, when 27 coal firms in Liège entered a cartel, the *Syndicat de Charbonnages Liégeois*. This fitted within a broader trend of cartellization in Belgium across many industries, the number of official Belgian cartels increased sharply during the 1880s and 1890s (as shown in Figure A10 in Appendix A). Cartels were allowed, and incorporated as legal entities. The executives of the member firms of the *Syndicat* met on a monthly basis to decide on joint output and prices for each coal type, with voting rights being a function of each firm's output. If a firm sold more than its quota, it had to pay a fine of 50 Belgian Francs per ton (compared to an average price of 9.7 Francs in 1898), and other violations of the cartel statutes were punishable at a fine of up to 1000 Fr. The cartel sold between 75 and 80% of total sales in the Liège bassin, the remainder being taken up by the dissenters. The cartel did not impose any quota on employment or other input expenditures. The cartel agreement was binding for a period of 5 years, and was renewed until 1935, when it was replaced by a national coal cartel, the *Office National des Charbons* (Vanthemsche, 1983).

[25]These employment shares are based on the industrial censuses of 1846 and 1896, allowing for comparison through the adaptation by Delabastita and Goos (2021). Production shares are based on Statistique de la Belgique (1858) and the *Annales de Mines de Belgique* (Administration des Mines, 1896, 505).

Production process

Extracting coal required, roughly speaking, three steps. First, the underground coal seam had to be reached by digging a mine shaft. Second, the coal had to be extracted. This was done manually by the miners, (*abatteurs*), with a pickaxe, and there was barely any mechanization of coal cutting in Belgium throughout our sample period.[26] Third, the lumps were hauled to the surface in containers or minecarts by mules and laborers, *hiercheurs*, often young children and women.[27] In contrast to the cutting process, coal haulage was gradually mechanized throughout our sample period, with the introduction of steam-powered underground mining locomotives, which were introduced around 1812. Two other forms of mechanization were crucial and increasingly adopted in the successful exploitation of Belgian coal mines throughout the 19$^{\text{th}}$ century. First, ventilation was important, as Belgian mines - and those in Liège in particular - were vulnerable to sudden releases of firedamp. This was done using steam-powered ventilation fans from the 1870s onwards. Second, water had to be pumped out of the mines, as many were located near rivers and other bodies of water. Early mechanization efforts, with the invention of the Newcomen pump, focused on this challenge. The increasing depth of Walloon mine pits required continued capital investments in these three technology types, which were typically steam-powered, but from 1893 onwards also electrically-powered (Gaier, 1988, 72).

There is some differentiation between the different types of coal being produced, mainly depending on its percentage of volatile matter, which determines its usage. Four coal types are distinguished in the data set, with volatile contents between 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 household for heating purposes. The second type was used in steam engines. The latter two types were used mainly for

[26] Pneumatic coal cutting machines would only be implemented in Liège coal mining around 1908. 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).

[27] An important innovation lied in the successful combination of interior rails and horse-drawn carriages in the second decade of the 19$^{\text{th}}$ century (Gaier, 1988, 79). The tight nature of many Liège mines made the introduction of equine power challenging, however, and experimentation with new rail and mine cart systems would increase its applicability throughout the 19$^{\text{th}}$ century (Caulier-Mathy, 1971, 217-219).

railroad locomotives, in combination with the other coal types. Mines often extracted a combination of these coal types, depending on the geological conditions of the mine location.

Labor relations

Partly due to due to the high population density in Belgium, manufacturing and mining firms could easily tap into a large reservoir of 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 19$^{\text{th}}$ century, as politicians held true to the liberal, *laissez-faire* principles on which Belgium was founded in 1830. Moreover, suffrage was conditional on wealth, with merely 1% of the population holding voting rights until 1893. This pushed questions on topics such as worker rights and living conditions to the political periphery.[28] At the root of this governmental indifference, was an unbridled confidence in the workings of the market mechanism. Illustrative of this spirit is the following quote by Minister of Public Works Alexandre Jamar, who summarized the government's position in 1869 as:

> *Let us say first of all that the intervention, in determining the wages, government or any other influence foreign to free competition of supply and demand, is a conception of which it is hardly need to point out the Utopian character. However painful be a situation created by the lowering of labor remuneration, we can only endure it. No coercive reaction is possible, however generous the principle may be. There is, in that order of ideas, nothing to try to modify the current state of things.* (Ministère des Travaux Publics, 1869, xiii)

Labor relations in 19$^{\text{th}}$-century Belgium were determined by laws that were put in place under French rule in the beginning of said century, and generally appear to have placed laborers in a unfavorable position[29] through one distinct institutional

[28] Indeed, international comparisons of legislation with regards to child labor, working time and factory inspection, consistently rank 19$^{\text{th}}$-century Belgium amongst least regulated countries in Europe (Huberman & Lewchuk, 2003).

[29] The particular case of Belgium was perhaps most strikingly summarized by Karl Marx, who called Belgium "the model state of continental constitutionalism, the snug, well-hedged, little paradise of the landlord, the capitalist, and the priest" (1985, 47).

feature: the inability of laborers to make any collective demands regarding working conditions.[30] More specifically, labor coalitions were prohibited until 1866, when this article was replaced by stark limitations on strikes.[31] The purpose of this legislation was to ensure freedom of labor, with proponents citing the need for an unbridled mechanism of supply and demand. Large-scale labor movements consequently knew little to no development for the larger part of the 19th century, or as Chlepner (1972, 27) aptly puts it: "it is not necessary to describe at length what does not exist".[32] Case in point is the syndical activity of Belgian coal mine workers. In the social movements of the 1880s and onward, coal mine workers were prominent participants, but they largely failed to materialize their demands.[33] 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).

In theory, this legislation also rendered collusion of employers illegal. However, the original law articles stipulated for much harsher punishment for laborer collusion, as well as included a vague and difficult-to-prove condition for employer collusion to be "unjust" and "abusive" to be punishable (Stevens, 1998, 402). Accordingly, employer syndicates did arise throughout the 19th century. Important in the case of Liège coal mining is that several mines united in the form of the *Union des charbonnages Liégeois* in 1840. We empirically examine the collusive role of this organization, as well as present more historical evidence in Section **??**.

Contemporary observations suggest that there were indeed rents in 19th-century labor markets to be colluded over. In his 1844 work on the causes of poverty in Belgium,

[30] Other than this feature and the aforementioned *livret*, most aspects of the labor relationship, such as working time, safety measures and method of wage payment, were largely agreed upon informally or orally (Van den Eeckhout, 2005).

[31] Strikes, the most important instrument of trade unions, remained illegal until 1921, when the article of 24 May 1921 was installed to warrant freedom of coalition.

[32] The few Belgian trade unions which did form, were exclusive of nature and focused on limiting labor supply in urban craft industries. Trade unions able to successfully mobilize large parts of the labor force would only arise in the last two decades of the century and only truly leave their mark on economic policy in the 20th century (Vandaele, 2004, 270-271).

[33] Indeed, the coal sector was by far the biggest social battleground in terms of numbers of strikes and employees involved at the turn of the 19th century. The share of successful strikes from the perspective of the labor force, however, was notably lower than the industry average - indicating a strong position of the employer (see Figure A6 in Appendix A).

journalist and government statistician Edouard Ducpétiaux devoted much attention to roles of “ill-defined liberty”, labor relations between workers and industrialist - who were in a “state of constant strike against each other” -, and the need for better agreement between labor supply and demand (Ducpétiaux, 1844, 18-34).[34]. In 1846, the chief engineer of the seventh mining district, Liège, took notice of coalitions from both employees and, more often, employers to influence wage levels (Ministère de l'Intérieur, 1846, 320). This short analysis of the institutional features of Belgian labor markets suggests that such commentaries might have had some truth to them.[35] In a context where policy interference was limited, where the limited legislation that was in place was discriminated against supply side of labor markets, and where employers openly cooperated in unions and cartels, collusion against labor supply might have been particularly abundant.

3.2 Data

Production and cost data

Our main data source is a novel data set which collects annual reports by the *Administration des Mines*, a state agency which employed engineers to annually inspect coal mines.[36] This data set was collected and cleaned by us, and we refer to Appendix B for all details concerning the data collection and processing. The *Administration* data is typically organized around mining concessions, in which the state grants permission to a person or firm to mine its natural resources. Concessions could be composed of multiple mines (production units). In theory, the same individual or firm could operate multiple concessions simultaneously, but in practice, however, this almost never happened in the Liège and Namur *bassins* as firms who owned multiple concessions immediately merged these into a single concession. Hence, we can assume that the

[34]Or, in his words: “The worker must not be able to lay down the law for the master; neither should the master be able to lay down the law to the worker” (Ducpétiaux, 1844, 26)

[35]It is also worth noting that the case of the mining worker received a prominent place in contemporary social commentary. In his seminal work on British living standards, Engels (1892, 241-260) dedicated a chapter to lament the “cheating” and “plundering” by the “coal kings”. In France, novelist Émile Zola centered his famous *Germinal* around the woes of the mine worker and the excesses of the bourgeoisie. Also in Belgium, contemporary critics have foregrounded the situation of laborers in coal mining. Socialist accounts have linked the miners' prominent role in the 1886 movements to their nefarious treatment by “parasites”, very much like in Zola's realist novel (Destrée & Vandervelde, 1898, 60).

[36]More historical background on this agency and the reports is in Appendix B.1.

concession-level unit of observation in the data corresponds to mutually independent firms.[37]

We observe both the total amount of coal extracted, as well as prices, both at the firm-year-level. Coal output and prices are reported separately for each of the four coal types. Employment (in numbers of employees and days worked) is observed at the firm-year-level, with a distinction between underground and surface workers.[38] For each of these respective categories, gross and net wages were also recorded.[39] Besides labor costs, the data reports firm-level expenditure data on, literally, 'non-labor ordinary expenses' and 'extraordinary expenses'.[40] We also observe the total horsepower for various machine types, up to 1899. To make this information tractable over the long period of observation, we aggregate them into two categories of machines: coal haulage (*extraction*) and water pumping (*épuisement*).[41] Furthermore, the count sheets also consistently record the use of horses in the mining activities, again up to 1899.

Additional data sets

We complement the production-cost data with various other data sources.[42] 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).

Data on the working population in the various provinces in our data set are taken from the ten-yearly population censuses, as adapted by Buyst (forthcoming). We linearly interpolate the employment estimates from these census years to obtain

[37] We motivate this assumption in depth in Appendix B.1.

[38] For some years, especially the earlier and later periods, the counts also differentiate workers based on their age and gender.

[39] For the earlier periods, the distinction between gross and net wages (typically due to participation in insurance schemes) was irrelevant.

[40] Wibail (1934) argues that the latter category include all expenses that involve 'mine construction, mine transformation and other expansion costs', which we interpret mainly as fixed capital costs. Further information on the construction of the cost variables can be found in Appendix B.1.

[41] For several years, we also have comprehensive information on use of horsepower in ventilation (*aérage*) and other purposes. These variables are, however, highly collinear with the other two mechanization variables.

[42] More information on the construction of these variables is provided in Appendix B.2.

yearly data. Next, 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 is 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 monetary variables in the data set.

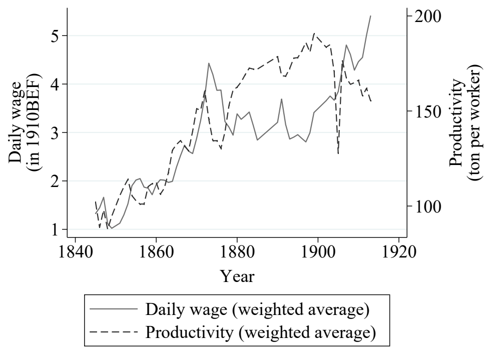
Descriptive evidence

Figure 2 presents some descriptive facts on the production/cost data. Figure 2(a) shows that average coal output per worker increased up to the 1890s, after which it started falling. Output growth, in Figure 2(b), also halted during the late 1890s. Wages grew rapidly, in line with labor productivity growth, until the 1870s. During the 1880s, wage growth was stagnant, before picking up again around 1890, together with a surge in coal prices. Figure 2(c) shows the total amount of horsepower at the Liège coal mines until 1900 in four categories: coal hauling machines ('transport'), water pumps, ventilation machines, and other technologies. There was a gradual mechanization throughout the entire time period. Figure 2(d) shows the evolution of the cost shares of all inputs over time. up to the late 1890s, the cost share of labor remained stable at around 60%, after which it declined to less then 50%. This decline was mainly due to an increasing cost share of intermediate inputs.

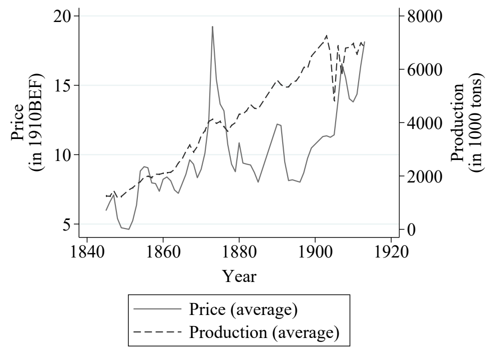
4 Empirical model of collusion in the coal industry

We tailor the general model from Section 2 to the context of the 19$^{\text{th}}$ century Belgian coal mining industry to quantify the degree of employer collusion and employer differentiation. The model consists of two parts: a model of how firms produce and choose inputs, and a model of how workers choose firms.

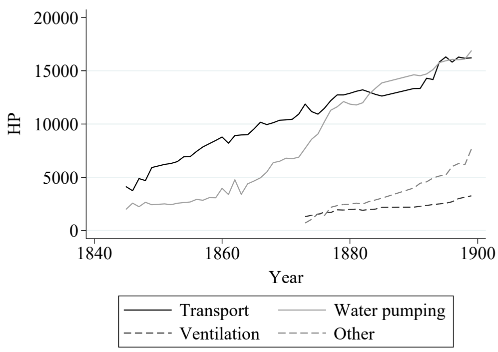
Figure 2: **Core variables in the *Administration de Mines* database**



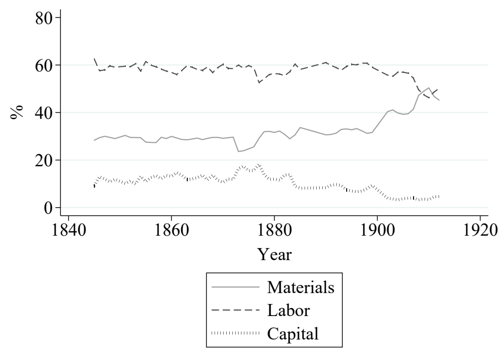
(a) Wages (left axis) and productivity (right axis)



(b) Coal prices (left axis) and production (right axis)



(c) Total mechanization, by type



(d) Cost shares (weighted average)

Source: Authors' database.

4.1 Labor demand

Production model

Output Q_{ft} indicates the tonnage of coal extracted during a given year by firm f, and P_{ft} is the mine-gate coal price per ton. There is limited differentiation in coal quality h_{ft}, which is observed.[43] Firms use two variable inputs: labor L_{ft}, which is measured as the average number of miners employed 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 lowercases.

Machines may have had non-Hicks-neutral effects, for instance because they were labor-saving. Our preferred specification of the production function in Equation (5) takes this into account through the coefficient β^{lk}. The output elasticities of labor and capital are equal to $\theta^l_{ft} = \beta^l + \beta^{lk} k_{ft}$ and $\theta^k_{ft} = \beta^k + \beta^{lk} l_{ft}$. The output elasticity of materials is assumed to be the same for all firms, $\theta^m_{ft} = \beta^m$. High-quality coal may be harder to extract, which is measured by the coefficient β^h.

$$q_{ft} = \beta^l l_{ft} + \beta^m m_{ft} + \beta^k k_{ft} + \beta^{lk} k_{ft} l_{ft} + \beta^h_{ft} h_{ft} + \omega_{ft} \tag{5}$$

Coal is sold at a price P_{ft}. We do not make any behavioral assumptions on demand for coal, price-setting and competition on coal markets, or the definition of coal markets. We allow for coal firms to be either price-takers or price-setters on the coal market. Hence, the markup of prices above marginal costs c_{ft}, $\mu_{ft} = \frac{P_{ft}}{c_{ft}}$, can flexibly vary across firms and over time.[44]

Identification

In order to identify the production function, we impose timing assumptions on firms' input choices, as proposed by Olley and Pakes (1996). Let the productivity transition be given by the AR(1) process in Equation (6a), with an unexpected productivity

[43] Quality differences are mainly due to variation in caloric content. We observe the breakdown of coal output into three quality categories.

[44] This markup is usually one or above one. If there is a markdown of wages below marginal costs and buyer power by the coal buyers, such as the railroads, it is even theoretically possible that markups are below one, which would not mean that coal firms are loss-making (due to the markdown of wages below marginal costs).

shock υ_{ft}.

$$\omega_{ft} = g(\omega_{ft-1}) + \upsilon_{ft} \tag{6a}$$

We assume that labor and intermediate inputs are variable and static inputs, and hence 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 $t-1$. Coal quality x_{ft} cannot be flexibly chosen after the productivity shock either.[45] More formally, we can thus write as following:

$$\mathbb{E}\Big[\upsilon_{ft}|(l_{fr-1}, m_{fr-1}, k_{fr}, h_{fr})\Big]_{r\in[2,\ldots,t]} = 0 \tag{6b}$$

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 (Levinsohn & Petrin, 2003; Ackerberg, Caves, & Frazer, 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), the productivity transition can be rewritten as a linear function with serial correlation ρ, Equation (6c). By taking ρ differences of Equation (6c), one can express the productivity shock υ_{ft} as a function of estimable coefficients without having to invert the input demand function.

$$\omega_{ft} = \rho\omega_{ft-1} + \upsilon_{ft} \tag{6c}$$

We pursue this approach as it allows us to not impose additional structure on the distribution of markups and markdowns across firms and over time. This comes at the cost of ruling out a richer productivity transition function $g(.)$, and of not coping with selection bias due to endogenous entry and exit. As is often noted in the literature, however, moving to an unbalanced panel, in which we do not select negatively on

[45]Coal quality is mainly determined by geological conditions that are exogenous to the firm once it is in operation.

market exit, already alleviates most concerns of selection bias.[46]

Estimation

Rewriting the moment conditions from Equation (6b), and only using the lags up to one year, the moment conditions are given by Equation (7).[47]

$$\mathbb{E}\Big[q_{ft} - \rho q_{ft-1} - \beta^0(1-\rho) - \beta^l(l_{ft} - \rho l_{ft-1}) -$$
$$\beta^m(m_{ft} - \rho m_{ft-1}) - \beta^k(k_{ft} - \rho k_{ft-1}) - \beta^{lk}(l_{ft}k_{ft} - \rho l_{ft-1}k_{ft-1}) - \beta^h(h_{ft} - \rho h_{ft-1})$$
$$|(l_{ft-1}, m_{ft-1}, k_{ft}, k_{ft-1}, l_{ft-1}k_{ft}, l_{ft-1}k_{ft-1}, h_{ft}, h_{ft-1})\Big] = 0 \quad (7)$$

As the estimation procedure requires lagged variables to be observed, we can estimate the model only on years for which the prior year is included in the data set as well, which reduces the sample size to 4003 observations. This also excludes firms which do not use capital or intermediate inputs, as logarithms are taken. Labor is measured as the number of workers times the number of days worked. Materials are measured using the 'ordinary expenses' variable, which is reported in the data. Capital is constructed by using the perpetual inventory method on the 'extraordinary expenses' category, which we describe more in detail in Appendix B.3. Coal quality is measured as the fraction of coal output that is 'fat' coal with a high caloric content.

Results

The production function estimates are in the top panel of Table 1 (i.e. Table 1(a)). We foreground two specifications of Equation (5): one which boils down to a Cobb-Douglas production function in which $\beta^{lk} = 0$, and another in which we allow for labor-saving and labor-augmenting technological change through β^{lk}. The former's estimates can be found in column (I), the latter's in column (II).

On average, elasticities with respect to the different inputs labor ($\hat{\beta}^l$), capital ($\hat{\beta}^k$) and materials ($\hat{\beta}^m$) are similar across both our specifications. These confirm the historical record that Belgian coal mining was indeed very labor intensive. Furthermore, allowing for factor-biased technology adoption indicates that capital investments were

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

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

labor-replacing, given the negative estimate of β^{lk}. This also aligns with the aforementioned mechanization of coal transport, in which steam power gradually replaced man power. Finally, it is also important to emphasize that, while the average elasticities are quite similar in both specifications, this hides substantial variation in elasticities at firm level. Given that we aim to estimate markdowns and collusion at firm level, it is really crucial to fully account for the labor-saving effects of technological change, as in the specification in column (II).

Table 1: **Model estimates**

		(I)		(II)	
(a) Production		Cobb-Douglas		Factor-biased	
		Est.	SE	Est.	SE
log(Labor)	β^l	0.648	0.217	0.994	0.261
log(Capital)	β^k	0.148	0.077	0.368	0.191
log(Materials)	β^m	0.251	0.115	0.230	0.103
log(Labor)*log(Capital)	β^{lk}			-0.023	0.014
R-squared		.940		.939	
Observations		3999		3999	
(b) Labor supply		Logit		Nested logit	
		Est.	SE	Est.	SE
Wage coefficient	α^w	2.209	0.739	2.991	1.442
Elasticity of substitution	σ			0.163	0.254
First stage F-stat (wage)		745.443		2080.052	
First stage F-stat (market share)				155.643	
R-squared		.008		.089	
Observations		4159		3874	

Notes: Bootstrapped standard errors, 50 iterations. Instruments for wage in labor supply model: horsepower used for water extraction at other mines in the same market, horsepower used for hauling at other mines in the same market, and TFP at other mines in the same market.

4.2 Labor supply

Worker utility and choices

We specify a differentiated employers Bertrand model in the spirit of Berry (1994) and Card et al. (2018). Each period, homogeneous workers i in a labor market ℓ choose to work for a coal firm f from a set of differentiated firms $\mathcal{F}_{\ell t}$. Every firm belongs to exactly one labor market ℓ, and firms are also grouped in geographical nests n, which are subsets of the market ℓ. The utility of each worker is given by Equation (8). Worker utility depends on the wage paid by the firm to all of its miners; firms do not wage discriminate within one type of workers. It also depends on observable firm characteristics $\mathbf{X}_{ft}$. We include the usage of technologies to extract water and haul coal, measured by their respective horsepower, as shifters of worker utility: miners presumably prefer working in mines with good water-extracting technology and with mechanized hauling. This is backed up by the fact that, as aforementioned, most mechanization was implemented to make miners' work easier and, more importantly, safer. Research on European coal mining safety in the second half of the 19$^{\text{th}}$ century has indeed reemphasized the important role of technology adoption in making mines less hazardous (Murray & Silvestre, 2015).[48] We also include the estimated total factor productivity level of each firm, ω_{ft} into the amenities vector, because firm productivity might be correlated with workplace safety (Gowrisankaran, He, Lutz, & Burgess, 2015). The vector ξ_{ft} contains latent sources of firm differentiation from the general point of view of the miners. The variable ν_{ift} is an unobserved worker-firm-specific shocks. Finally, each nest of firms has a characteristic ζ_{nt}, and there is an elasticity of substitution $0 < \sigma < 1$ that measures the within-nest correlation in utilities: if $\sigma = 0$, all products are symmetric substitutes, if σ approaches one, products within the same segment are perfect substitutes. The coefficients $\boldsymbol{\alpha}^x$ measure the degree to which miners care about the different covariates in the utility function.

$$U_{ift} = \alpha^w W_{ft}^l + \boldsymbol{\alpha}^x \mathbf{X}_{ft} + \boldsymbol{\zeta}_{ft} + \zeta_{nt} + (1-\sigma)\nu_{ift} \tag{8}$$

Workers have an outside option of working in any other industry than coal mining

[48] Additionally, the more modern, large-scale coal firms in Liège were also at the forefront of the adoption of sanitary amenities such as lavoratories (Gaier, 1988, 187).

in the same market, of which the utility is normalized to zero. As documented in Section 2.4, search and switching costs are assumed to be zero, and the model is static: workers only care about their current utility and can switch firms or switch to the outside option in any period t without cost.

The labor market share of firm f is denoted $s^l_{ft} \equiv \frac{L_{ft}}{L_{\ell t}}$, with $L_{\ell t}$ being the total employment across all firms and the outside option. The market share of the outside option is s^l_{0t}. Assuming that the shock ν_{ift} is EV(1) distributed leads to the labor supply function in Equation (9):

$$s^l_{ft} - s^l_{0t} = \alpha^w W^l_{ft} + \sigma s^l_{ft|n} \boldsymbol{\alpha}^x \mathbf{X}_{ft} + \boldsymbol{\zeta}_{ft} \tag{9}$$

The inverse wage elasticity of labor supply ψ^L_{fft} is given by:

$$\psi^l_{fft} = 1 + (\alpha^w(\frac{1}{1-\sigma} - \frac{\sigma}{1-\sigma} s_{ft|n} - s^l_{ft})W_{ft})^{-1} \tag{10}$$

Identification

One cannot simply estimate Equation (9) using OLS because firms take into account their attractiveness $\boldsymbol{\zeta}_{ft}$ when choosing wages. In order to identify the labor supply functions (10), we need shifters of labor demand that do not enter the worker's utility function. We rely on characteristics space of the other employers in the same market as demand shifters at firm f, similarly to the instruments suggested by Berry, Levinsohn, and Pakes (1995). More specifically, we rely on the observable amenities of other firms in the same labor markets (number of water extraction machines, number of coal hauling machines, and total factor productivity) as demand shifters for firm f. The assumption is that the usage of these technologies and productivity at competing firms affect equilibrium wages, as they affect worker utility, but do not change the utility of workers at firm f, conditional on the wage rate, productivity, and technologies used at firm f. We denoted the averages of these technology characteristics at other mines in the same *arrondissement* (district), municipality and town into the instrumental variables vector $\mathbf{Z}_{ft}$.

Labor market definitions

It is important to characterize labor markets in a correct manner (for a discussion, see Manning & Petrongolo, 2017). We define labor markets at the province level, with sub-provincial nests at the 2-digit postal code level, which roughly corresponded to 'arrondissements' (groups of municipalities). A survey of all commuting workers at the two largest coal mines in the Liège basin in 1905 by Mahaim (1911) shows that 93.3% of workers were recruited from the same province and 64% from the same 2-digit postal code. The remaining workers did not live in the provinces of the other bassins (Hainaut or Namur), but rather in nearby Limburg, where no coal mines were present at the time. Hence, we can safely assume that the Liège and Namur coal basins were isolated labor markets, which did not compete with each other for workers. The average worker lived 5.54 km from the mine, and 90% of the workers lived closer than 16 km from the mine. The cumulative distribution of commuting distances is in Figure A9 (Appendix A). Most workers walked to the mine (84.7%), 13.9% commuted daily by train, and 1.4% commuted during the weekend and lived close to the mine during the week, away from their family.[49] We add the sub-provincial nests because firms that are located close to each other are probably tighter competitors than firms that are located at the opposite sides within the same province. In Liège, there were on average 60 firms at the province-level, and 12 per 2-digit postal code, and in Namur 19 and 6, respectively. The average province-level employment share within coal mining was 1.7% in Liège and 5.3% in Namur, and 11.0% and 17.1% at the 2-digit postal code level. Given that workers could choose to work outside of coal mining as well, we define the total market size L_{0t} as the working population in each province, rather than the number of coal miners.[50] The outside option is hence equal to the share of the working population in each province that is not employed in coal mining.

Estimation

In the observable covariates matrix $\mathbf{X}_{ft}$, we include the horsepower of water extraction machines, and the horsepower coal hauling machines. As was discussed before, these

[49]We return to the role of transportation networks in Appendix C.1, in which we present a robustness check to validate our labor market definition.

[50]We observe this number only in census years, and infer it using linear interpolation for the remaining years.

were likely to affect miner utility. In addition, we also include the average wage in non-mining industries as a covariate, as this shifts the utility derived from the outside option. This wage level is the same for all firms in a given year. We also include total industry sales across all manufacturing industries, as a measure for the business cycle, which could again affects the outside option of the workers.

Results

The estimates of the labor supply model are in Table 1(b). In column (I), we set the elasticity of substitution σ equal to zero, which corresponds to the standard logit model. In column (II), we also estimate the elasticity of substitution, which is hence a nested logit model. Standard errors are block-bootstrapped within firms with 50 iterations. In both cases, the chosen instruments perform well, and the estimated coefficients are generally economically and statistically significant.

4.3 Markdowns

Having established the empirical approaches from the labor demand (i.e. the production approach) and the labor supply sides, we can now estimate collusion by comparing said methods. The actual markdowns are estimated through the production-side approach, through which we can directly compare the marginal product of labor with its remuneration. Next, we can then use the obtained labor supply elasticities from the labor supply approach to define counter-factual markdowns under different conduct assumptions. Bringing these elements together, we are finally able to pinpoint the parameter of interest: the level of employer collusion.

Actual markdown

We allow for oligopsony power on the labor market, but assume that intermediate input prices are exogenous to each individual firm. Given that Belgian coal firms were well-integrated in the Belgian manufacturing sector, both from a supply chain and a geographic perspective, it is indeed reasonable to assume that coal firms had to compete with other industrial sectors for material inputs. The cost-side estimate for the wage markdown μ^L_{ft} is equal to the right-hand side of Equation (4):

$$\mu^l_{ft} = \frac{\theta^l_{ft} W^m_{ft} M_{ft}}{\theta^m_{ft} W^l_{ft} L_{ft}}$$

The markup μ^Q_{ft} can be calculated by looking at the wedge between the marginal product and price of intermediate inputs:

$$\mu^q_{ft} = \frac{\theta^m_{ft}}{\frac{W^m_{ft} M_{ft}}{P_{ft} Q_{ft}}}$$

The estimates are in Table 2(a): using the Cobb-Douglas model, the markdown is estimated to be 2.3 on average, which implies that the marginal product of labor is 2.3 times larger than wages. Wages are hence marked down below the marginal product of miners by 56%. The 90% confidence interval on the average markdown lies between 1.6 and 3.9. With the factor-biased model, the average markdown is lower at 1.9 with a CI on [1.6;4.0]. The estimates hence show a large degree of oligopsony power over workers. The average coal price markup is estimated is 0.74, with a 90% confidence interval of [0.51;1.08]. The point estimate indicates that coal prices are 25% *lower* than marginal costs, but this does not imply that mines are loss-making: they also exert profits from the wedge between marginal costs and wages. The markup ratio is not significantly different from one, so we cannot reject that coal prices are equal to marginal costs. This is consistent with the institutional feature that coal markets were integrated and unconcentrated, and with the fact that coal is a not very differentiated product. Indeed, recent historical research has highlighted the increasingly integrated nature of the European coal market throughout the 19$^{\text{th}}$ century (Murray & Silvestre, 2020). Our results are consistent with this finding. The yearly evolution of average markups and markdowns can be found in Figure F.2 in Appendix D.

Non-collusive markdown

The wage markdown level in the absence of employer collusion can be found by setting the ownership matrix Λ_t to the identity matrix in Equation (4). The non-collusive wage markdown of firm f, $\underline{\mu^l_{ft}}$ is then equal to the inverse wage elasticity of labor

Table 2: **Markdowns and markups**

(a) Production approach		(I) Cobb-Douglas Est.	CI05	CI95	(II) Factor-Biased Est.	CI05	CI95
Avg. markdown	μ^l	1.480	0.406	1.858	1.849	0.489	2.264
Avg. markup	μ^q	0.876	0.788	2.102	0.801	0.720	1.855
(b) Labor supply approach		Logit Est.	CI05	CI95	Nested logit Est.	CI05	CI95
Avg. labor supply elasticity	ψ^l	1.210	1.122	1.377	1.133	1.038	1.375

Notes: Bootstrapped standard errors, 50 iterations.

supply, which was computed in Equation (10):

$$\underline{\mu^l_{ft}} = \psi^l_{fft}$$

Results are in column (I) of Table 2(b). In the nested logit model, which is the baseline model, the non-collusive markdown is estimated at 1.15, which implies that the marginal product of miners is 15% above their wage. The 90% confidence interval lies between 1.058 and 1.682. For the standard logit model, the markdown is 1.17 with a CI on [1.071;1.315]. The non-collusive markdown is hence estimated to be much lower than the cost-side markdown estimated presented above.

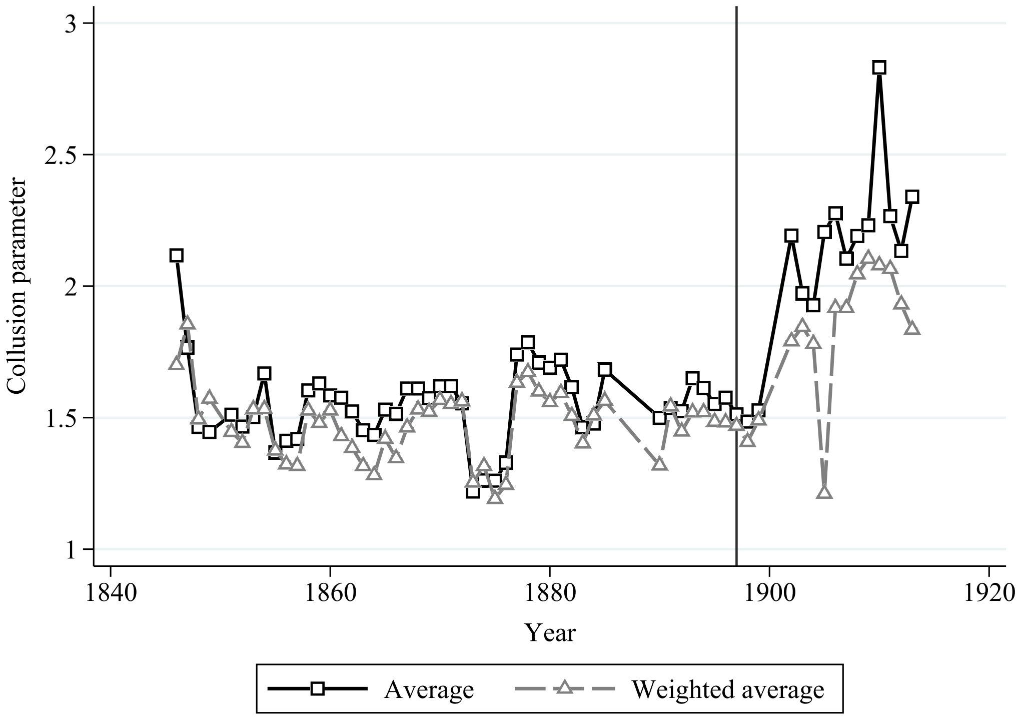
4.4 Employer collusion: results

Level and trend

Given Section 4.3's findings on the actual markdown μ^j_{ft} (estimated from the labor demand side) and the non-collusive markdown $\underline{\mu^j_{ft}}$ (estimated from the labor supply side), we can now calculate collusion as $\mu^j_{ft}/\underline{\mu^j_{ft}}$. We plot the yearly evolution of this ratio in Figure 4.

Two important stylized facts about employer collusion emerge in this analysis. First, collusion was a persistent and ever-present feature of industrial labor markets in 19$^{\text{th}}$-century Belgium, as our collusion parameter is consistently higher than one. This is remarkable on its own in the context of a coal industry where many employers and a lot of entry and exit was present, and indicates that employers did take advantage of the institutional setting to collude at a large scale. Second, we see a marked rise in collusion after the turn of the century. This structural break is confirmed by the OLS regressions in Table 3. Unsurprisingly, this trend co-occured with the emergence of cartelization in the European coal industry. We return to this mechanism in Section 5.

Figure 3: **Average employer collusion in Liège and Namur-based coal mining, 1845-1913**



Notes: The vertical line at 1897 denotes the start of the cartel period in the Liège coal industry.

Finally, it is worth noting that the entire matrix Λ can in principle be estimated for by solving the system of Equations (4). Denoting the vector of wage markdowns as M_t^L and the error term as Ξ, this system of equations in matrix notation gives:

$$M_t^L = \Lambda_t \Psi_t + \Xi_t$$

However, the large number of firms results in a very large number of coefficients that would need to be estimated. Even if we assume that collusion weights do not change over time and are symmetric across firms, meaning that $\lambda_{fjt} = \lambda jft \quad \forall f, j$, we need

Table 3: **Evolution of labor market collusion**

	(I)		(II)	
	log(Collusion)			
	Est.	SE	Est.	SE
Year	0.006	0.002		
1(1860 <Year<1879)			0.018	0.069
1(1880<Year<1899)			0.112	0.092
1(1900<Year<1913)			0.435	0.109
Observations	4418		4418	
R-squared	.068		.096	

Notes: Reference category is the period between 1845-1859. Bootstrapped standard errors, 50 iterations.

to estimate $N(N-1)/2$ coefficients. With 227 firms, that gives 25,651 unknown coefficients, compared to a data set size of 8,780. Hence, we restrict our analysis to the firm-year specific collusion level κ_{ft}, rather than estimating every pair-wise collusion weight λ_{fjt}.

Employers' associations

We now turn to empirically assessing our measure of employer collusion using observable drivers of employer collusion, to provide additional empirical support for our results. A first and obvious possible driver of employer collusion is the emergence of institutionalized employer interaction in the form of employers' associations. In 1840, local coal mines united in the form the the *Union des Charbonnages Liégeois*.[51] One of the main tasks of this union was to "coordinate salary fluctuations, in order to avoid the danger of temporarily high salaries which could harm the entire coal region" (De Leener, 1904, 234). This cooperation would later be formalized in 1868 with the establishment of organization's statutes and the inclusion of other mines and metalworks, under the name of the *Union des charbonnages, mines et usines métal-*

[51] Similar initiatives surfaced in the other Belgian coal *bassins*. The other region in our data set, *Basse-Sambre*, was recognized by more small-scale, family-run firms, lacking formal cohesion. Charleroi's employers' association attempted to gain control over this area, but without widespread success in terms of membership (see Appendix B.2 for more details).

lurgiques de la province de Liège. Its committee would convene on a monthly basis to discuss recent events, and to propose courses of actions to serve the common good. While this collective had the rather vague pretense of defending the interests of the local coal and metal industries, their yearly reports reveal a wide range of topics in which they attempted to pressure policy decisions. In the context of labor relations, the *Union* sought to specifically fight government intervention in issues such as child labor[52] and female labor[53], as well as any form of labor inspection[54] or concessions to labor unions.[55] Furthermore, they lobbied strongly in favor of the controversial *livret*.[56] Overall, contemporary economists regarded the Union as a prime meeting location for Liège employers to coordinate all kinds of employment decisions (De Leener, 1909, 138). This becomes clear when one considers the Union's reaction to changes in the legal framework of industrial labor. For example, the Union called to life a monthly commission to formulate "uniform rules" as to the application of the new labor accident insurance law of 1903 (Union des charbonnages (...), 1906, 30).

In what follows, we assess whether the behavior as documented by anecdotal evidence translated into empirically tractable levels of collusion. A straightforward test is to assess the relationship between mines' relationship to the employers' association and their degree of collusion. Based on internal communication by the *Union*, we created a yearly identification variable of coalition members, tracing mines' participation throughout the period of observation.[57] Accordingly, we regress firm-level degree of collusion on a binary measure of the firm's membership status to the employers'

[52]"It is only by descending in the mines at an early age that young miners acquire what is called the 'instinct of the coal miner"' (Union des charbonnages (...), 1872, 131). "All these jobs, it must be admitted, are not very strenuous and it would be difficult, if not sometimes impossible, for their execution, to replace the children by adults who, for the most part, would not submit to them" (Union des charbonnages (...), 1887, 124).

[53]"We protest again against the regulation of the work of the adult woman, which constitutes a flagrant violation of individual freedom" (Union des charbonnages (...), 1889, 48).

[54]In a letter to the new-founded Ministry of Industry and Labor, the Union's committee deemed a new law on mine inspection "useless", because it would do little to prevent individual accidents, and "dangerous", because it would be a cause of conflict in industrial relations (Union des charbonnages (...), 1896, 15).

[55]According to the Union, such concessions would be "a question of placing an instrument of war in the hands of the workers". "As for the mining delegates, their intervention will be a cause of strife, struggles, false maneuvers" (Union des charbonnages (...), 1895, 17).

[56]"Without *livret*, the workers will be able to abandon the establishments en masse and throw disruption in industry"; "when the benefits of instruction and education penetrate further among them, we will be the first to applaud this progressive movement" (Union des charbonnages (...), 1869, 10-11).

[57]For more information, we refer to Appendix B.2.

association.

The results of this exercise are presented in Table 4(a). We find that members of employer unions (in the form of the employers' association of Liège coal firms) were indeed foremost culprits of employer collusion. Membership directly implied an average increase in collusion of approximately 10 to 17%. Tacit collusion was also important, as a competitor within the same district being a member of the *Union* signified an approximate increase in collusion of 16 to 21%. In summary, these findings strongly align with the presented anecdotal evidence, and underline the soundness of our collusion identification approach.

External competition and the business cycle

Another likely driver of changes in collusion over time is the business cycle. The reason for this intuitive: when demand for coal is high, demand for labor follows, and incentive to deviate from the collectively-agreed wage level changes. This mechanism is akin to cartel theory that relates to collusion on product markets, much like in the seminal paper of Rotemberg and Saloner (1986).[58] The extensive time coverage of our data set implies that we can assess collusion over various stages of coal demand. The Belgian economy was an active participant in trade, and its coal sector was consequently highly sensitive to the international business cycle, as well as foreign competition.[59]. The mines in our sample generally suffered from inferior geological conditions, and struggled to maintain productivity vis-a-vis the adjacent and more productive Hainaut and German coal regions.

In Table 4(b), we regress our yearly collusion parameter in the form of the weighted average on two yearly measures of the business cycle. In column (I), we regress the collusion variable on a yearly measure of Belgian coal output, capturing cyclical shocks on the Belgian coal industry. In column (II), we use an industry-wide measure in the form of the industrial production index of Gadisseur (1979). Both specifications confirm the aforementioned and expected pattern: employer collusion was negatively

[58] In these types of models, collusion is always anti-cyclical: deviation from cartel prices in times of high demand implies higher expected profits, as well as lower costs of punishment by cartel members.

[59] This is apparent in Belgian production and price data (Figures A1 and A2 respectively in Appendix A) Of particular interest are the boom and bust period of the 1870s and 1880s, as well as the stagnating production and productivity after the turn of century due to increasing mine exhaustion.

correlated with the business cycle.

Table 4: **Employer collusion: covariates**

(a) Employer associations	(I) log(Collusion) Est.	SE	(II) Est.	SE
1(Employer union)	0.167	0.063	0.103	0.063
1(Competitor in employer union)	0.209	0.072	0.157	0.074
Fixed effects	Year		Year+Province	
Observations	2141		2141	
R-squared	.113		.195	
(b) Business cycle	log(Weighted average of Collusion) Est.	SE	Est.	SE
Recession	-0.304	0.186	-0.278	0.190
Measure	Coal industry output		All industries output	
Observations	61		61	
R-squared	.35		.26	

Notes: Bootstrapped standard errors, 50 iterations.

5 Downstream cartels and labor market collusion

In the previous section, we documented a strong increase in employer collusion against workers from around 1900 onwards. This coincides roughly with the start of the Liège coal market cartel in 1897, and we investigate the relationship between this product market cartel and labor market collusion in this section.

5.1 Empirical evidence

We start with empirical evidence, as we observe the coal cartel membership lists. Denote $\mathcal{N}_t$ the set of coal firms in year t, and $\mathcal{C}_t \in \mathcal{N}_t$ the set of cartel members. Indicating the membership of a cartel as $C_{ft} = I(f \in \mathcal{C}_t)$, we compare a dependent variable of interest y_{ft} between the cartel firms and other firms before and after the start of the cartel in 1897, with d_t and d_f being year and firm dummies.

$$y_{ft} = a_1 C_{ft} + a_2 C_{ft} I(t > 1897) + d_t + d_f + v_{ft}$$

We estimate this difference-in-differences equation for log of the coal price markup μ^q_{ft}, which includes the degree of collusion on the product market, and the log of our labor market collusion variable κ_{ft} in Table 5. Column (I) only includes year dummies, column (II) also includes firm dummies.

The estimates in Table 5(a) show that markups increased by 20 to 25% at the cartel firms compared to the dissenters after 1898.[60] The cartel was hence successful in increasing markups at the member firms. This micro-level evidence adds nuance to the historical view that coal cartels of the early 20th century were largely ineffective at a macro level (Murray & Silvestre, 2020, 697).

In Table 5(b), we use the same difference-in-differences framework to compare the evolution of labor market collusion between the cartel and non-cartel firms. Here, we find very different results. As was already shown in Table 3, wage collusion increased across all firms after 1898. However, it did not increase more at the cartel firms compared to the dissenters, but to the contrary increased *less* compared to the dissenters. In the next section, section 5.2, we provide an explanation for this seemingly contradictory result.

5.2 Mechanism

The participants to the coal cartel agree to produce a reduced output $Q^*_t = \sum_{f \in \mathcal{C}_t}$, which is sold at a higher price P^*_t. If marginal costs would be constant and capacity unlimited, dissenters would slightly undercut the cartel price and take up the entire market, causing the cartel to unravel. In reality, however, marginal costs are upward-sloping due to the existence of oligopsony power (making the labor supply curve faced by each firm to be upward-sloping), which gives the dissenters an incentive to slightly undercut the cartel, but limit their production. This can be seen in Figure 4a. The cartel mainly started to lower its output from 1903 onwards, at which point the dissenters start undercutting the cartel price, as shown in Figure 4b. The market share

[60] This stems from the fact that $\exp(0.186) - 1 = 0.204$, and $\exp(0.225) - 1 = 0.252$.

Table 5: **Coal cartel**

	(I)		(II)	
(a) Markup	log(Markup)			
	Est.	SE	Est.	SE
I(Cartel) * I(Year>1898)	0.222	0.065	0.275	0.080
Fixed effects	Year		Firm+Year	
Observations	4687		4687	
R-squared	.078		.091	
(b) Labor collusion	log(Labor collusion)			
	Est.	SE	Est.	SE
I(Cartel) * I(Year>1898)	-0.210	0.043	-0.187	0.053
Fixed effects	Year		Firm+Year	
Observations	4402		4402	
R-squared	.122		.119	
(c) Labor-material ratio	log(Labor/Materials)			
	Est.	SE	Est.	SE
I(Cartel) * I(Year>1898)	-0.278	0.049	-0.234	0.062
Fixed effects	Year		Firm+Year	
Observations	4729		4729	
R-squared	.538		.474	

Notes: Bootstrapped standard errors, 50 iterations.

of the dissenters increases modestly. The firms within the cartel cannot change their price and output, because they would face steep fines when doing so. This is an equilibrium as long as the increase in profits due to higher prices at the cartel make up for the lost market share to the dissenters.

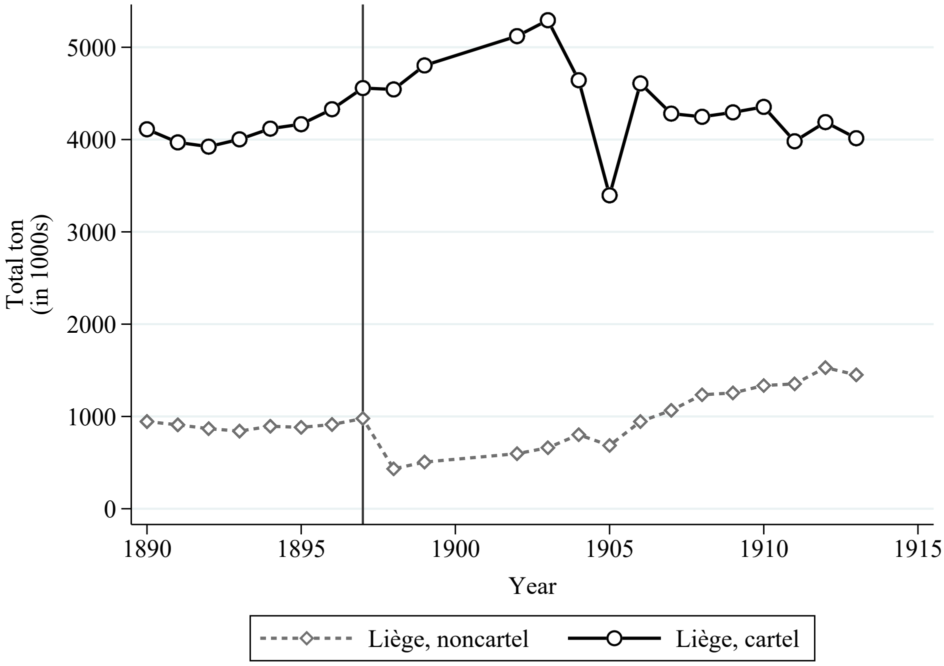
Now let us turn to the labor market. First, given that output falls at the cartel firms, labor falls as well. This reduction leads to an increased markdown, and hence higher collusion λ. Second, note that dissenter firms can continue colluding on the labor market, even if not colluding on the coal market: as noted before, firms can raise output without necessarily raising employment if they substitute towards intermediate inputs. Suppose that the firms which dissent from the coal cartel by lowering coal prices and raising output keep colluding with the other firms on the labor market. In order to keep employment and wages at the collusive level, they need to substitute *more* towards intermediate inputs than the cartel firms. Given that these firms push down employment by more compared to the non-collusive employment level, in order to keep colluding on the labor market, their degree of labor market collusion increases proportionally by more than the cartel firms. Some evidence for this is in Table 5(c). The labor-to-material ratio indeed falls by 24.3% more for cartel dissenters compared to the cartel firms.

6 Conclusions

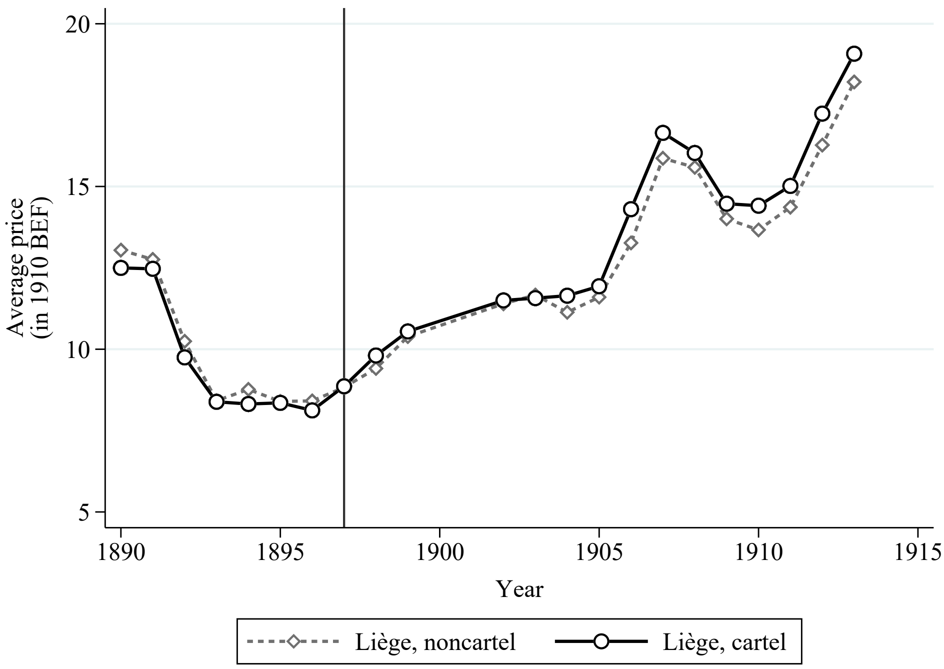
In this paper, we point to a substantial body of both current-day and historical evidence to argue that employer collusion is a credible source of labor market power. To make research on such forms of anti-competitive behavior empirically tractable, this paper proposes an empirical approach to measure collusion behavior using data on production, costs, wages and employment. This method is then applied to a newly digitized data set based on the archives of the Belgian mining department, the *Administration des Mines*, whose supervisory duties translated into consistent, micro-level engineer reports covering all coal mining production activities throughout a large part of Belgium's industrialization. Our estimates reveal the existence of widespread and persistent collusion in industrial labor markets. Our collusion parameter is also closely related to observable, historical examples of labor market collusion in the form of employers' associations. Furthermore, we find that collusion was particularly prominent in times of economic upswings, as incentives to collude against workers became higher, which is in line with a modified version of the Rotemberg and Saloner model (1986).

We foreground the crucial role of interaction between collusion upstream (on the labor market) and downstream (on the product market). First, we identify the marked impact of the *Syndicat de Charbonnages Liégeois* on the mark-ups of its members through limitations on coal production. The latter, however, has far-reaching effects on labor market collusion as well. Reductions in production translated into reduction in labor inputs as well, increasing collusion. Importantly, noncartel firms were able to uphold (tacit) collusion at the labor market alongside cartel members and increase

Figure 4: **Cartel and noncartel firms' evolution of output and prices, 1890-1913**



(a) Output



(b) Price

Notes: The vertical lines at 1897 denote the start of the cartel period in the Liège coal industry.

production simultaneously through input substitution. As a consequence, this mechanism grants us new insights on the differentiated but connected nature of upstream and downstream collusion. In this sense, concerns regarding increasing collusion on product markets might have important labor market consequences as well, and this finding emphasizes the policy relevance of battling anti-competitive practices.

Our findings on the ubiquitous nature of employer collusion thus highlight the importance of an active antitrust policy regarding labor market issues. Not only is the rise of labor monopsony a topic worth of attention to policy makers (Naidu et al., 2018), battling employer collusion requires active detection of hidden practices such as wage fixing, sharing wage information and "no-poaching" agreements. In this context, research on the detection of employer collusion undoubtedly has an important role to play.

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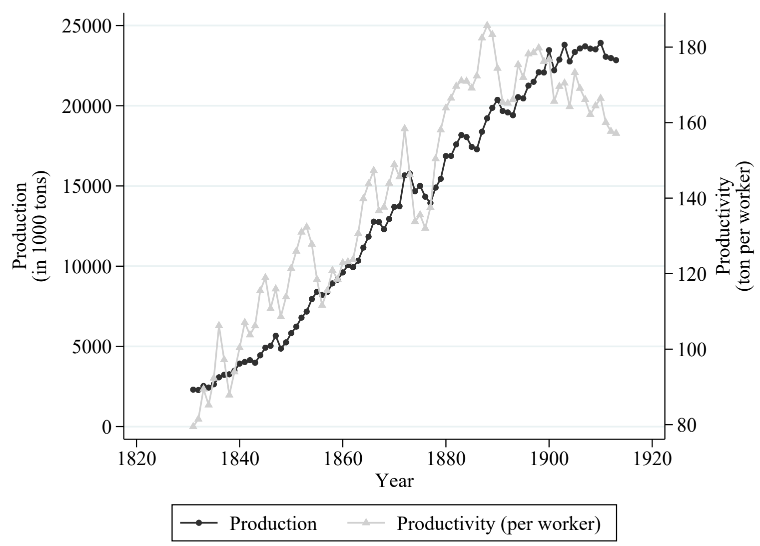
Appendices

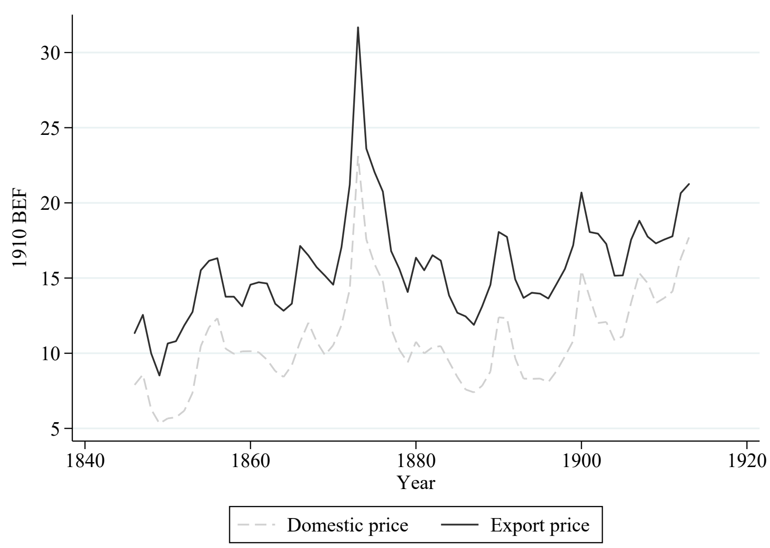
A The Belgian coal industry in the long 19th century

Figure A1: **Total production (left axis) and production per worker (right axis) in Belgian coal mining, 1831-1913**



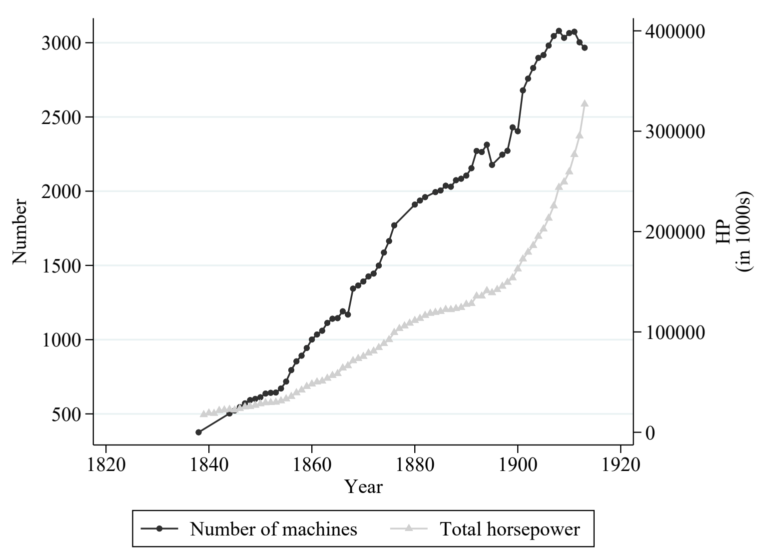
Source: Production statistics are from the published accounts of the *Administration des Mines*, as cited in Gadisseur (1979).

Figure A2: **Domestic and export prices of coal per ton in Belgian coal mining, 1831-1913**



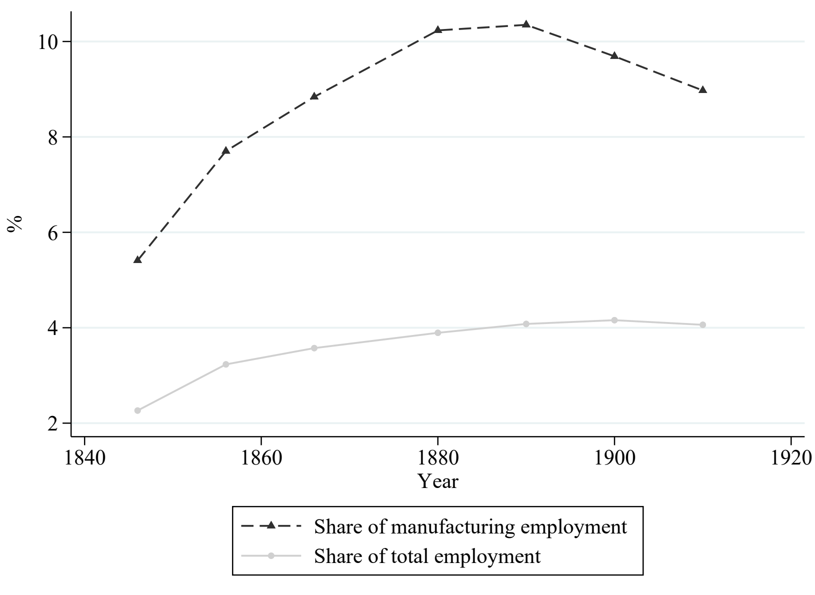
Source: Domestic prices are from Wibail (1934). Export prices are from the official trade statistics, as cited in Degrève (1982).

Figure A3: **Capital accumulation in Belgian coal mining in terms of number of machines (left axis) and total horsepower installed (right axis), 1838-1913**



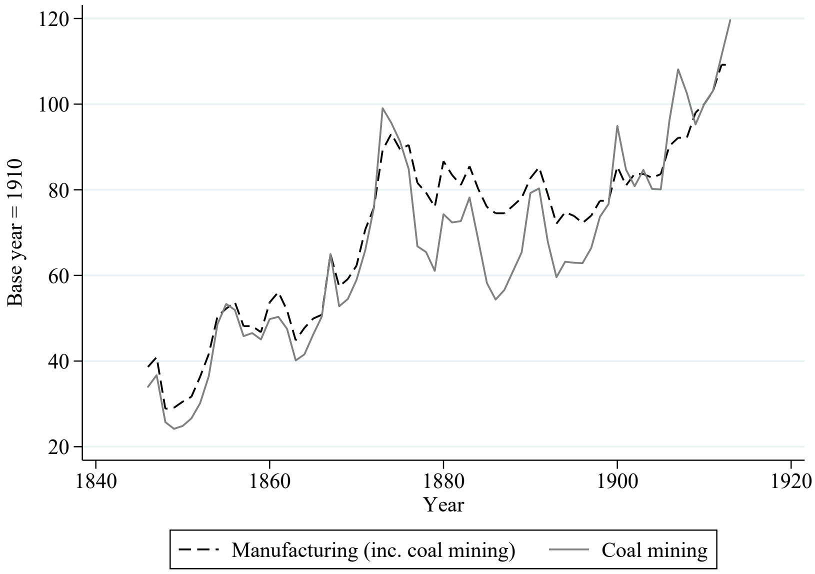
Source: Mechanization statistics are from the published accounts of the *Administration des Mines*, as cited in Gadisseur (1979).

Figure A4: **Share of coal mining activities in Belgian manufacturing and total employment, 1846-1910**



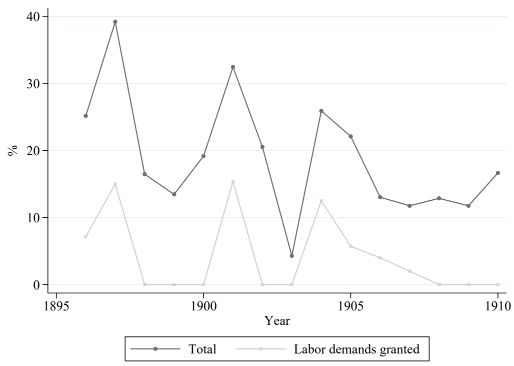
Source: Coal mining employment is from the published accounts of the *Administration des Mines*, as cited in Gadisseur (1979). Manufacturing and total employment are based on Buyst (forthcoming).

Figure A5: **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 A6: **Share of coal mining employees involved in Belgian strikes, 1896-1910**



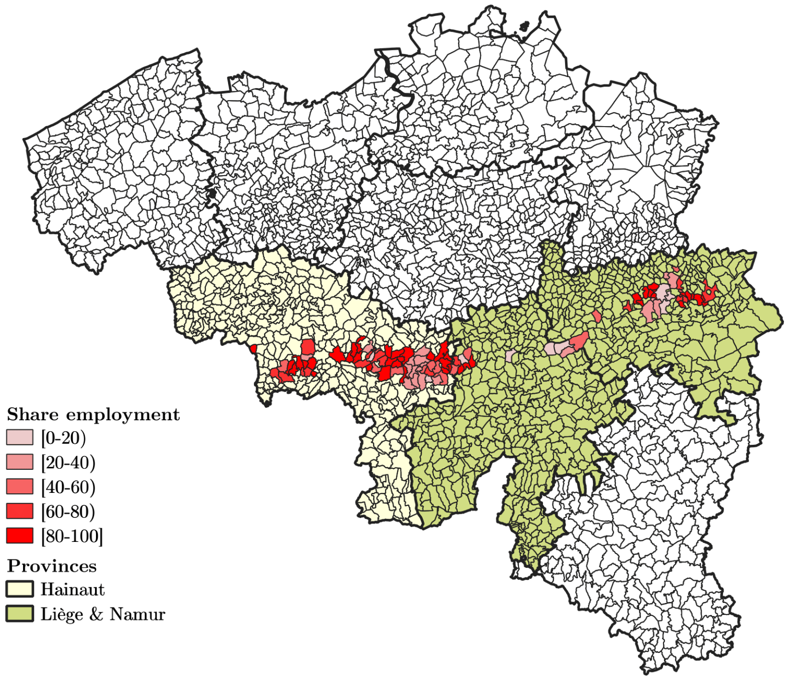
(a) Number of strikes

(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.

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

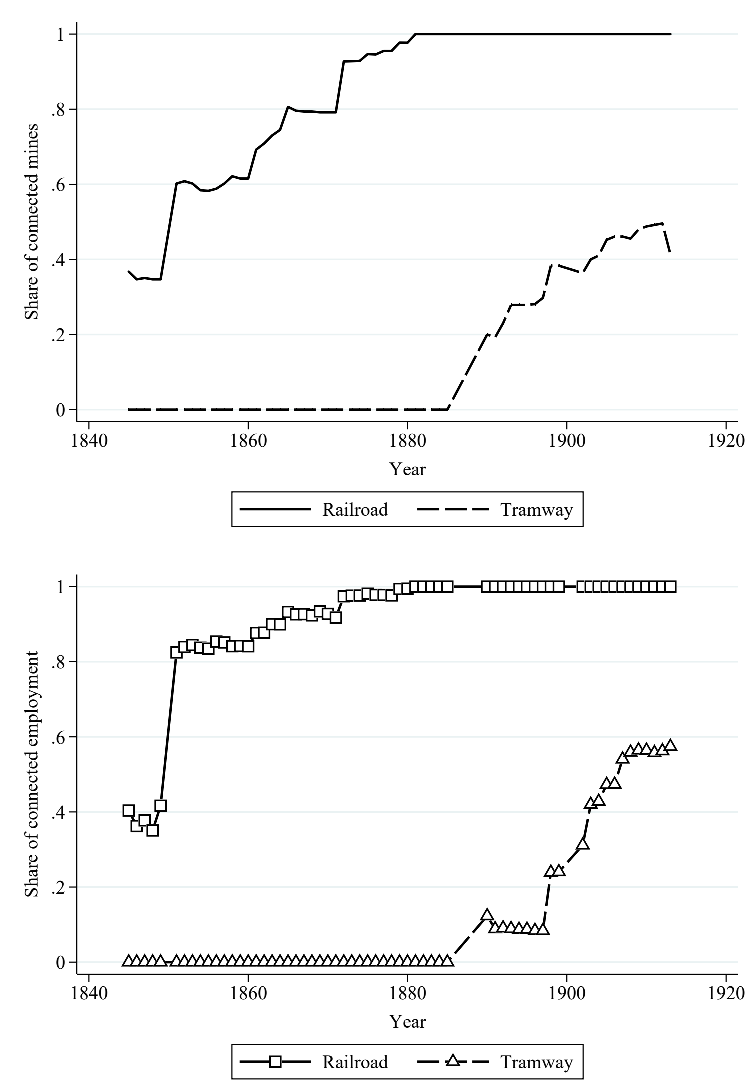
Figure A7: **Map of share of coal employment of total industrial manual employment, 1896**



Notes: Historical community borders of 1890.

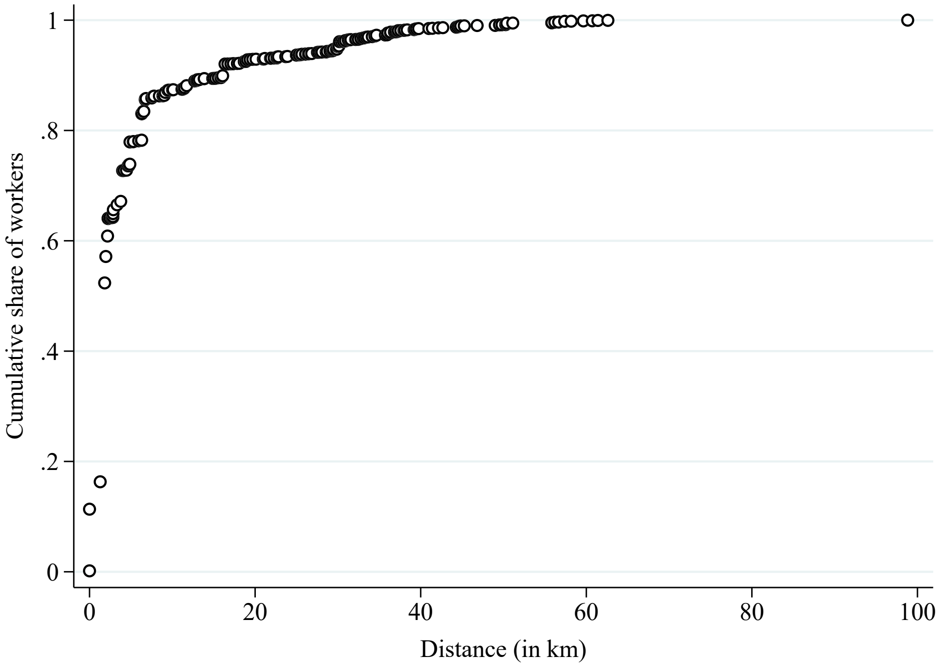
Source: Data are adapted from the industrial census of 1896 (Office du Travail, 1896a, 1896b). This source was digitized by the *Quetelet Center for Quantitative Historical Research* (Ghent University).

Figure A8: **Expansion of the railroad and tramway networks, connection to Liège and Namur mines, 1845-1913**



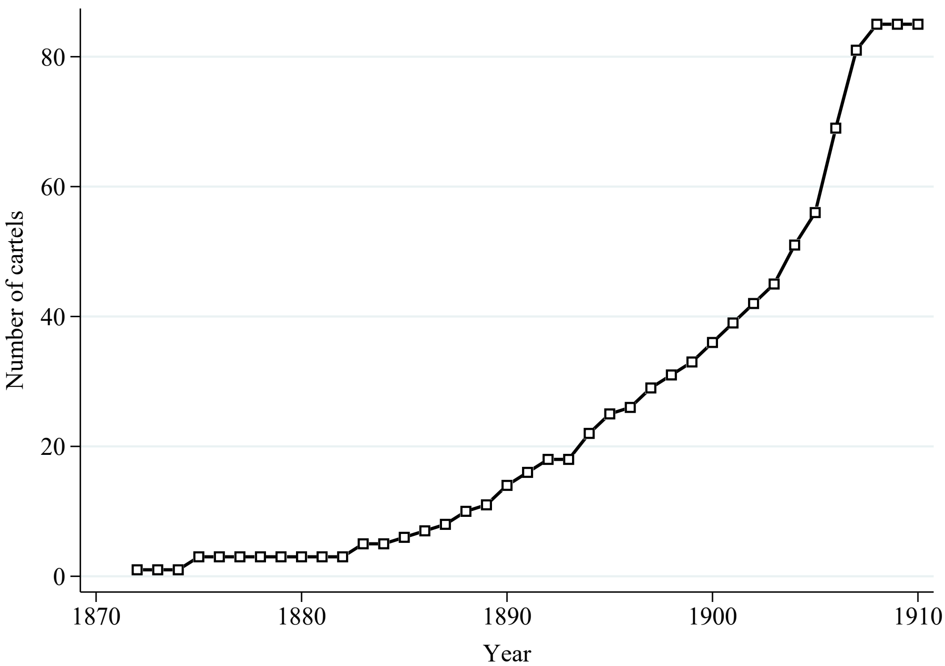
Source: Authors' database. Opening dates of Belgian train stations are provided by the *Quetelet Center for Quantitative Historical Research* (Ghent University). For more information, see Section B.2.

Figure A9: **Commuting distances in 1905**



Source: Own calculations based on the survey by Mahaim (1911) at the Liège-based firms *Ougrée-Marihaye* and *Espérance-Bonne-Fortune*.

Figure A10: **Number of cartels in Belgium,**



Source: Own calculations based on cartel descriptions in De Leener (1908).

B Data

B.1 *Administration des Mines* archives

Historical background

The institutional framework of Belgian coal mining was installed 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).[61] 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).[62] In fact, the new Belgian government would call to life the *Conseil des Mines de Belgique* by the law of 2 May 1837, which would fill the institutional gap left behind by its French counterpart (Geerkens et al., 2020, 293).

Due to its French roots, the close supervision of the mining industry presents us with a valuable exception on the aforementioned *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

[61]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.

[62]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).

straightforward integration of the yearly accounts into a uniform data structure.[63]

Construction of the variables

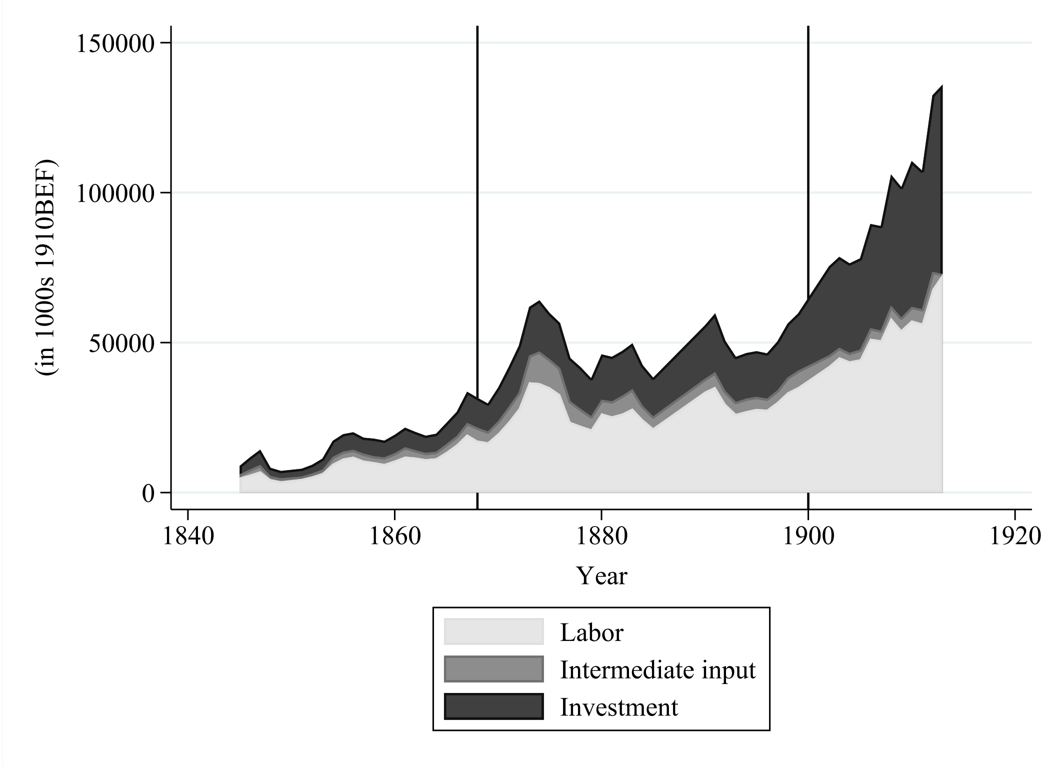
In this section, we provide a structural overview of how we constructed the variables for our empirical analysis. As outlined above, the data collected by the mining engineers are remarkably consistent over the almost-70-year period. In the case of the expenditure statistics, however, some changes in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

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

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 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.

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

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



Source: Authors' database.

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[64], and this implies that our estimates of employer collusion are potentially biased upwards by within-firm coordination. We argue, however, that this is not a likely driver behind our observations on the ubiquity of collusive wage-setting. 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.[65] 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 the 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

[64]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.*

[65]Multiple-concession firms appear to have been located primarily in the *Bassin du Couchant de Mons*, non-surprisingly the area in which universal banks had the strongest hold on the coal industry (we return to this issue below).

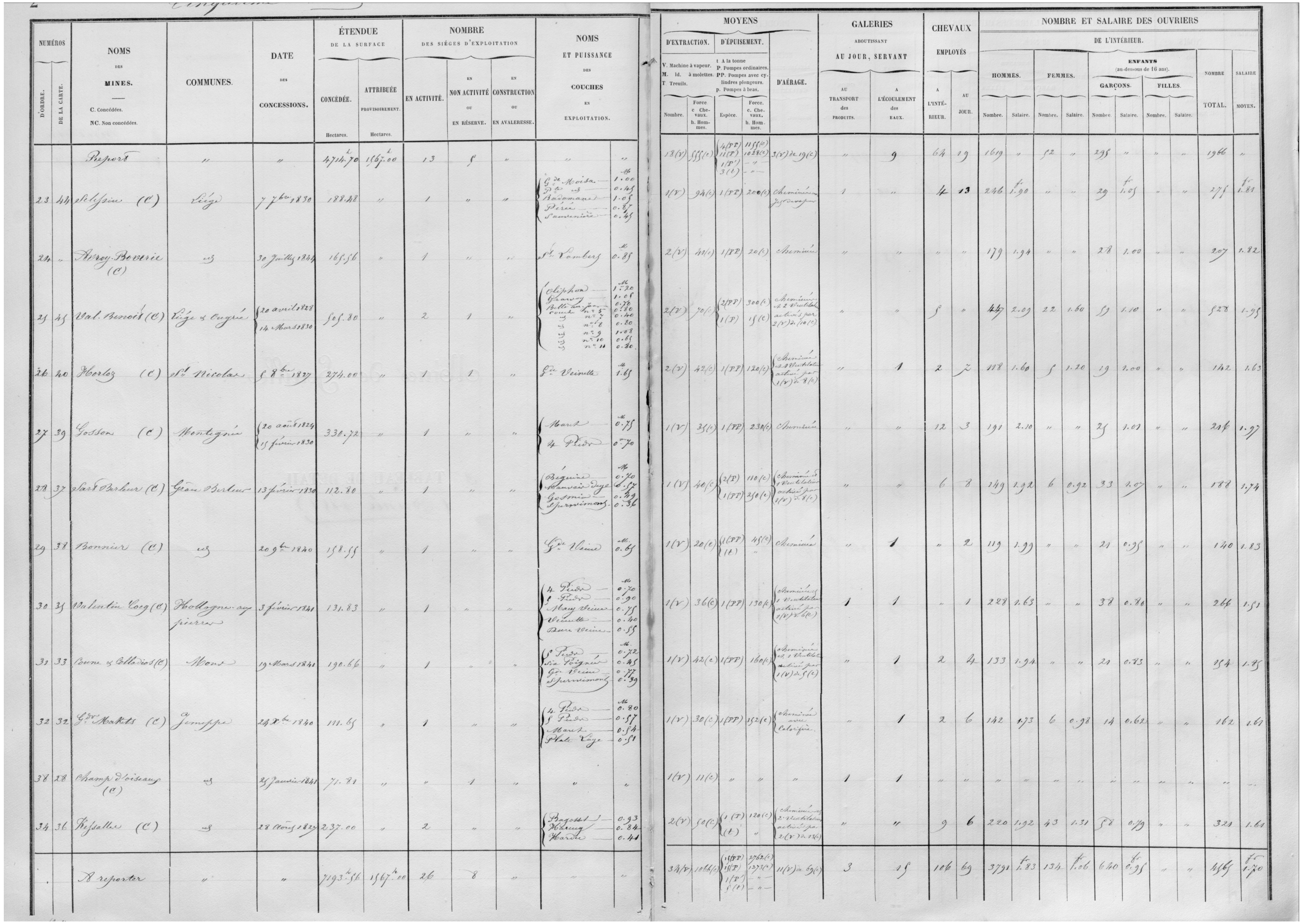
public coal companies.

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".[66] 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 actually followed by the unification of the firms' concessions as well.[67]

[66] This is a 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).

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

Figure B.2: **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**

Bassin & 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**

Bassin & 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

⚒ Membership of the *Union des charbonnages*

To quantify membership of the *l'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.

⚒ Employers' associations in Namur

Most *bassins* in Belgium had their own respective employers' organizations, much like the *Union*. However, the smaller and diluted 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* (Association charbonnière (...), 1931, 30). Membership lists of said organization reveal that the reach of these efforts was very limited in terms of membership, however.

⚒ 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. Combining these two pieces of information, we were able to retrace all coal mines' approximate year of connection to the Belgian railroad network.

⚒ 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, 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 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 lied around 13%, we set $\delta = 0.13$ in order to calculate the capital stock. For years in which investment data are missing, we linearly interpolate missing investments.

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.

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

Next, 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 are 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.3: **Depreciation**

(a) Machine horsepower	(I) Not invested		(II) Invested	
	Est.	SE	Est.	SE
$1-\delta$	0.873	0.008	1.017	0.003
R-squared	.782		.974	
Observations	3550		3277	

(b) Equine horsepower	(I) Not invested		(II) Invested	
	Est.	SE	Est.	SE
$1-\delta$	0.849	0.009	0.993	0.005
R-squared	.721		.934	
Observations	3550		3277	

C Robustness checks

C.1 Labor market frictions

We propose the following robustness checks to assess the role of search frictions in our empirical approach. In our main analysis, we assumed that search frictions play a negligible role. To provide further empirical support to this claim, we assess the relationship between our collusion estimates and observable variation in search frictions. If our assumption is correct, we should see little to no correlation between both variables.

A first shift in search frictions is the roll-out of the Belgian train network. Connection to the railroad network allows local employees to switch to their outside option at a lower cost, which decreases oligopsony power.[68] Under the assumption that search frictions were already sufficiently low, however, we thus expect this channel to have little quantitative impact on our collusion results.

The case of Belgium is a particularly interesting case to study such impacts of the roll-out of a transportation network, as the country was an early and keen adopter of train transportation network. Starting from the inauguration of the first train line on the European Continent, the world's densest transportation network of that era was rolled out throughout the 19$^{\text{th}}$ century. This made that the Belgian labor force became increasingly mobile, reinforced by a government-subsided worker ticketing program (Huberman, 2008). A town's or mine's connection to the train network thus had a potentially vast impact on local labor market dynamics and the potential for collusion.

We empirically assess this channel as follows. The vector $\mathbf{D}_{ft}^{rr}$ contains dummies that indicate whether a coal mine is located in a town that is connected to the railroad network and the tramway network at time t.[69] We regress log employer collusion on these dummies and alternatively include mine, year, and both mine and year fixed effects on its right hand side:

$$\log(\kappa_{ft}) = \boldsymbol{\delta}\mathbf{D}_{ft}^{rr} + \upsilon_{ft}$$

[68]See also the study by Brooks, Kaboski, Kondo, Li, and Qian (2021), who find pro-competitive effects of the expansion of highways in India.

[69]We refer to Figure A8 in Appendix A for a graphical representation of this data.

The results of this exercise can be retrieved in Table D.1(a). We find little evidence that a firm's connection to the train transport network had a substantial negative negative effect on its collusive behavior. This confirms our aforementioned assumption that search costs were rather low in Belgian labor markets of the industrial era, and that our definition of labor markets as in Section 4.2 is accurate.

Second, we investigate the role of the abolition of the *livret*. The employers could confiscate a worker's passport and thus impose search frictions on employees. As shown in Table D.1(b), however, we do not find that its abolition in 1883 has neither a significant nor a negative effect on our collusion estimates. Hence, we conclude that search frictions are not a substantial driver of employer collusion as measured through our proposed empirical approach.

Table D.1: **Variation in search frictions and employer collusion**

(a) Transport infrastructure	log(Collusion)			
	Est.	SE	Est.	SE
1(Railroad connection)	-0.105	0.062	-0.093	0.053
1(Tramway connection)	0.046	0.051	0.159	0.064
Fixed effects	Year		Firm	
Observations	3032		3032	
R-squared	.050		.035	

(b) Abolition of livret	log(Collusion)			
	Est.	SE	Est.	SE
1(Year $\geq$ 1883)	0.054	0.036	0.042	0.028
Fixed effects	Year		Firm	
Observations	1139		1139	
R-squared	.003		.002	

Notes: Bootstrapped standard errors, 50 iterations.

D Additional figures and tables

Figure F.1: **Markdowns and markups**

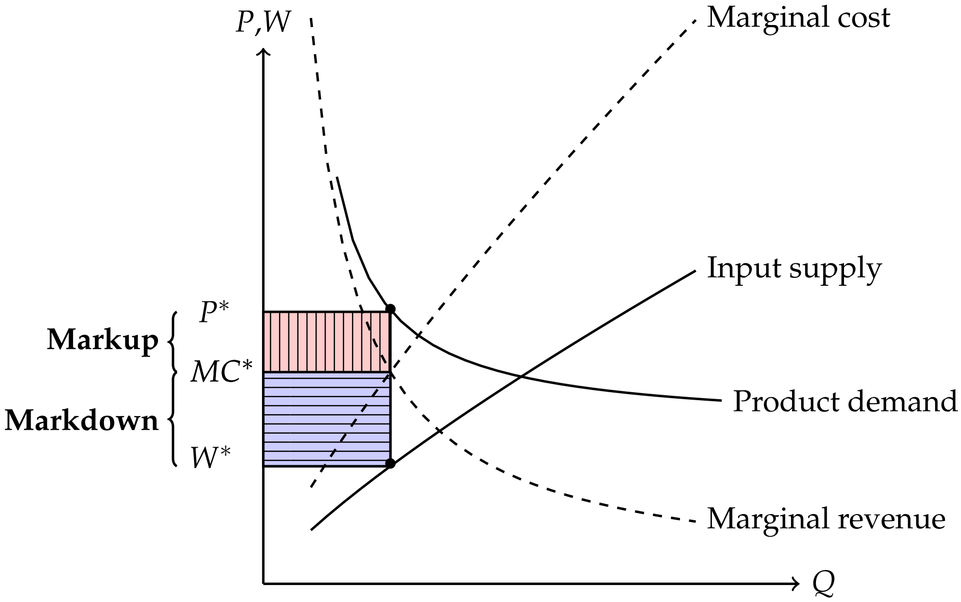


Figure F.2: **Evolution of markdowns and markups in Liège and Namur-based coal mining, 1845-1913**