Online appendix to:

Colluding Against Workers

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A Derivations and theory

A.1 Markups and markdowns in the general model

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

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

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

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

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

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

Rearranging terms gives the following expression:

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

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

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

Similar to the derivation in the main text, the first-order condition for materials is identical to the markup derivation in De Loecker and Warzynski (2012). Given that intermediate input prices are exogenous to firms, we have that:

$$W_{ft}^{m} = \frac{\partial Q_{ft}}{\partial M_{ft}} MC_{ft}$$

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

$$\mu_{ft} = \frac{\theta_{ft}^{m}}{\alpha_{ft}^{m}}$$

A.2 Conduct identification in the general model

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

$$1 + \psi_{ft}^{l} + \sum_{g \in \mathcal{F}_{i(f)t} \setminus f} \left(\lambda_{fgt} \psi_{fgt}^{l} \frac{L_{gt} W_{gt}^{l}}{L_{ft} W_{ft}^{l}}\right) = \frac{\theta_{ft}^{l} \alpha_{ft}^{m}}{\theta_{ft}^{m} \alpha_{ft}^{l}} \tag{A.1}$$

A.3 Symmetry assumption in the counterfactuals

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

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

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

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

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

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

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

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

A.4 Labor supply elasticities

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

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

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

$$\frac{\partial L_{ft}}{\partial W_{it}^l}\frac{W_{it}^l}{L_{ft}} = \frac{1}{\Psi^l s_{ft}^l} \tag{A.3b}$$

A.5 Equilibrium expressions for the counterfactuals

A.5.1 Model with exogenous prices

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

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

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

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

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

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

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

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

A.5.2 Model with endogenous prices

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

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

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

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

Equating labor demand and supply results in:

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

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

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

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

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

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

B Data

B.1 *Administration des Mines* archives

B.1.1 Historical background

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

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

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

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

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

B.1.2 Construction of the variables

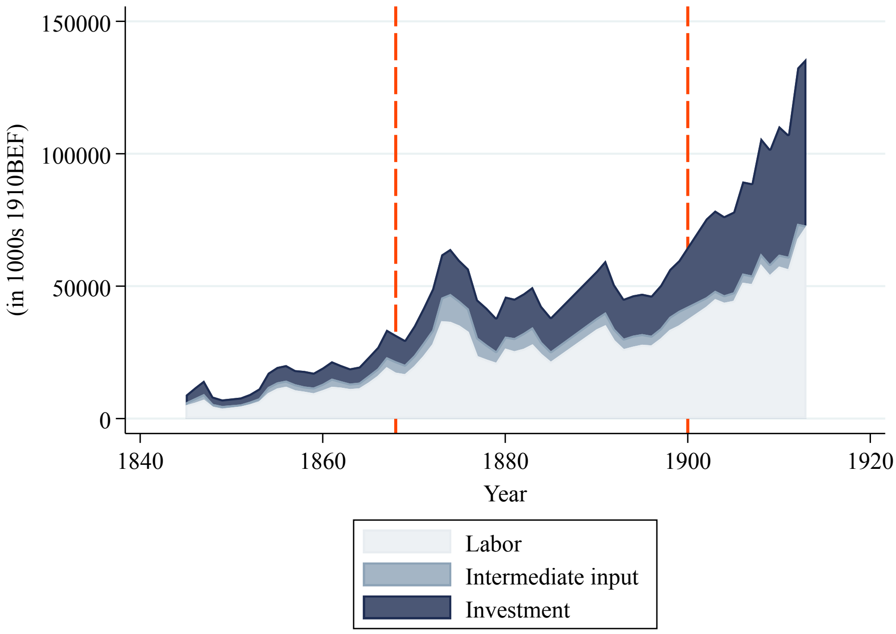
In this section, we provide a structural overview of how we constructed the variables for our empirical analysis. As outlined above, the data collected by the mining engineers are remarkably consistent over the almost-70-year period. In the case of the expenditure statistics, however, some changes in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

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

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

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

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



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

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

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

B.1.3 Concession and firm composition

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

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

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

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

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

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

public coal companies.

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

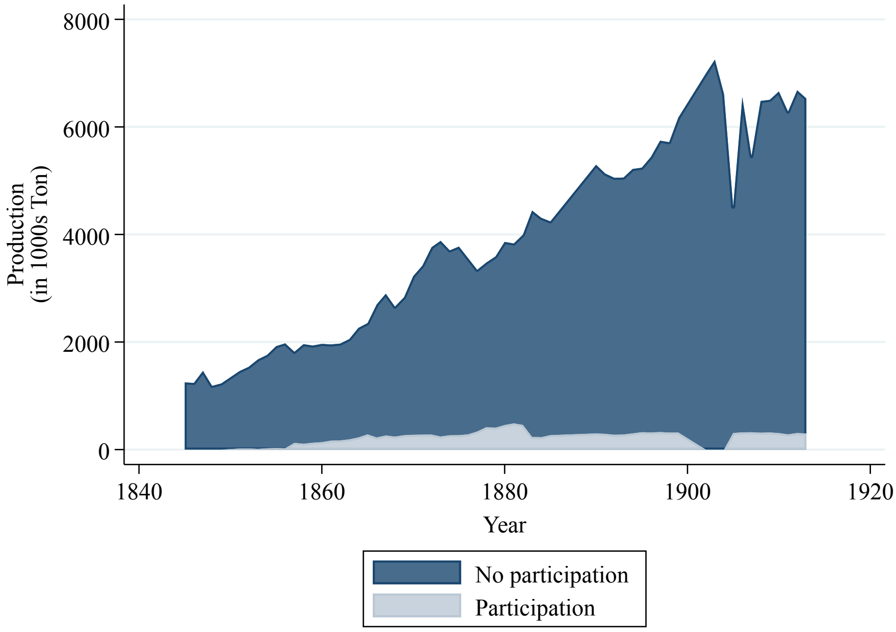
A more prevalent connection between the concessions in our database appeared to have in been the form of *common* and, more importantly, *inter-firm ownership*. Collusion due to *common ownership* is probable if powerful investment banks had a strong hand in multiple exploitations. As discussed in Section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

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

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

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

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

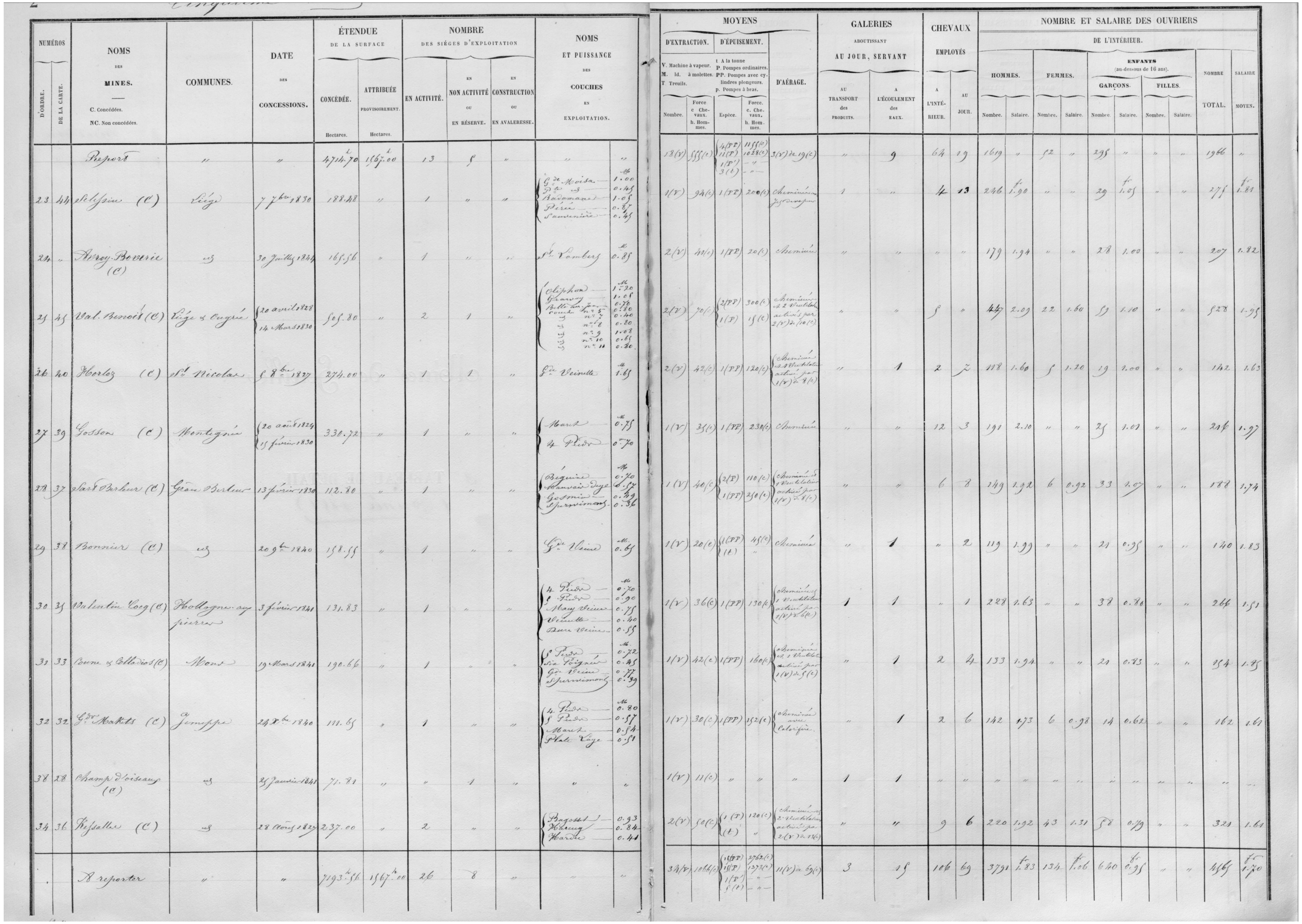


Notes: This graph shows total output produced by coal firms in which the *Société Générale* participated, and by all other coal firms.
Source: Authors' database and the yearbooks of the *Société Générale de Belgique* (SCOB).

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

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

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



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

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

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

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

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

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

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

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

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

B.2 Other sources

B.2.1 Membership of the *Union des charbonnages*

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

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

B.2.2 Employers' associations in Namur

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

B.2.3 Access to the railroad network

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

B.2.4 Cartel membership

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

B.3 Constructing the capital stock

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

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

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

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

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

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

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

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

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

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

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

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

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

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

B.4 Summary statistics

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

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

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

B.5 Sample sizes

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

Table B.6: **Sample sizes**

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

Panel B: Market-level:	N	Table
(i) All	2624	
(ii) Observe l_{ft}, w^l_{ft} + instruments	1990	1(c)

C Robustness checks

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

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

C.1 Production function: extensions and robustness

C.1.1 Non-constant output elasticities

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

The markup expressions from the main text generalize to:

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

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

Similarly, the markdown equation becomes:

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

C.1.2 Imposing a returns to scale parameter

In the main text, we estimate a version of the production function where we impose a value for the scale parameter $\varsigma \equiv \beta^l + \beta^m + \beta^k$, rather than letting it vary freely. This allows estimating the model with more precision, but comes at the cost of imposing an assumption on the degree of returns to scale. The production function in logs that needs to be estimated becomes Equation C.1.

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

Using the same timing assumptions as imposed throughout the main text, the moment conditions are given by Equation (C.2). We now need to estimate one parameter less than in the version of the model that freely estimates returns to scale.

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

In the main text, we imposed a scale parameter of $\varsigma = 1.05$. In this appendix we test robustness of the results for three different returns to scale parameters, $\varsigma = 1.00$, $\varsigma = 1.10$, and $\varsigma = 1.15$. Table C.1 shows the resulting production function and markdown/markup estimates. The first column imposes constant returns to scale, $\varsigma = 1.00$, the second and third columns allow for increasing returns to scale, $\varsigma = 1.10$, and $\varsigma = 1.15$. Imposing constant returns to scale leads to a negative capital elasticity and to a wage markdown below one, meaning that workers are paid more than their marginal revenue product, both of which seem highly unlikely. However, our main model (noisily) estimated returns to scale to be increasing, at 1.07. If we calibrate returns to scale to be increasing at either 1.10 or 1.15, we find output elasticities and markdown/markup estimates that are much in line with the main model, but more precisely estimated. The capital coefficient is estimated at 0.102 in the version of the model with $\varsigma = 1.05$, which is in the main text, and reduces to 0.055 and 0.010 when imposing higher returns to scale of $\varsigma = 1.10$ and $\varsigma = 1.15$ respectively. In Figure C.1, we plot the evolution of the corresponding collusion index for the four different values of the returns to scale parameter. In all three specifications with increasing returns to scale, we find that the collusion parameter lies on average above the Cournot lower bound and increases sharply after the cartel's introduction. Imposing $\varsigma = 1.05$ leads to an increase of the markdown to the fully collusive markdown bound after 1897, under $\varsigma = 1.10$ and $\varsigma = 1.15$ it increases to around 1.5 times the fully collusive markdown bound.

C.1.3 Translog production function

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

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

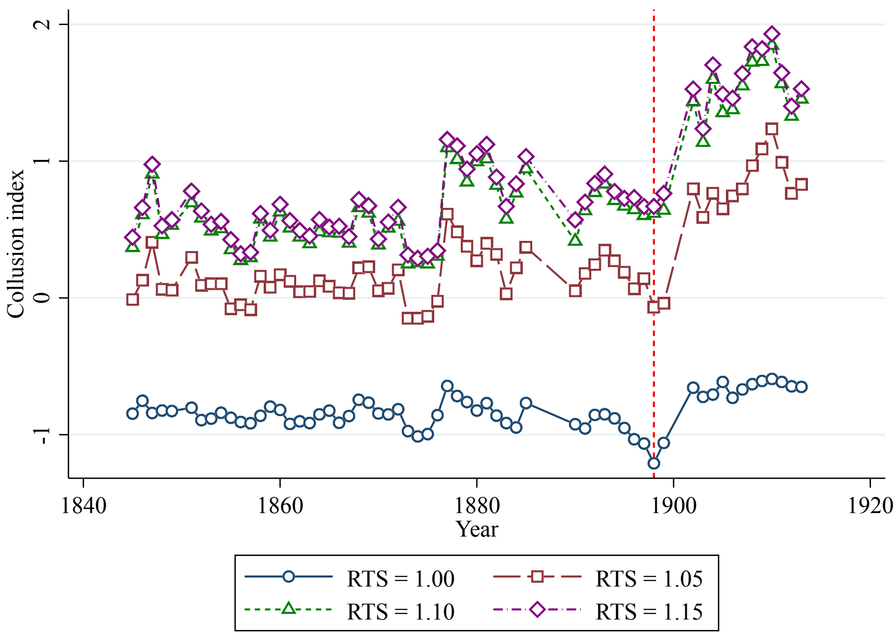
We estimate this equation in Table C.11. The resulting employer collusion series is plotted as red squares in Figure C.3. Collusion is now estimated to fall in between

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

	$\varsigma = 1$		$\varsigma = 1.10$		$\varsigma = 1.15$	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
Labor	0.550	0.031	0.731	0.046	0.770	0.054
Materials	0.460	0.040	0.214	0.044	0.220	0.050
Capital	-0.009	0.036	0.055	0.032	0.010	0.030
Median wage markdown	0.633	0.086	1.806	0.562	1.852	0.836
Median price markup	1.454	0.125	0.677	0.140	0.696	0.158
Hansen J-test	1.35		2.67		4.25	
Hansen J-test p-value	.507		.262		.119	
Observations	4005		4005		4005	

Notes: This table shows the production function estimates when imposing a returns to scale parameter $\varsigma \equiv \beta^l + \beta^m + \beta^k$. The first column imposes constant returns to scale, $\varsigma = 1.00$, the second and third columns allow for increasing returns to scale, $\varsigma = 1.10$, and $\varsigma = 1.15$ respectively. Block-bootstrapped standard errors are computed with 200 iterations.

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



Notes: This graph shows the evolution of the median of our collusion measure, $\hat{\lambda}$, when imposing a returns to scale parameter $\varsigma \equiv \beta^l + \beta^m + \beta^k$: (i) constant returns to scale ($\varsigma = 1.00$) (ii) increasing returns to scale ($\varsigma = 1.05$) (iii) increasing returns to scale ($\varsigma = 1.1$), and (iii) increasing returns to scale ($\varsigma = 1.15$).

1845 and 1897, but it still increases substantially after the introduction of the cartel in 1897. Given that none of the interaction terms in the translog production function are statistically significant, we keep the Cobb-Douglas function as our main specification.

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

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

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

C.1.4 Time-varying production function

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

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

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

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

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

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

C.1.5 Input and product differentiation

In the main text, we relied on the assumption that coal is a homogeneous product. In this section, we examine extensions of the model in which we allow for coal differentiation. First, if inputs and output are vertically differentiated and if higher quality inputs

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

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

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

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

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

Panel A: Output elasticities	log(Output)		log(Output)	
	Est.	S.E.	Est.	S.E.
log(Labor)	0.750	0.222	0.702	0.324
log(Materials)	0.252	0.127	0.226	0.130
log(Capital)	0.148	0.047	0.154	0.071
Serial correlation	0.933	0.111	0.870	0.188
Method	Price control		Quality control	
R-squared	.699		.937	
Observations	4001		4005	

Panel B: Markups	Est.	S.E.	Est.	S.E.
Average markdown	1.707	0.539	1.780	0.570
Average markup	0.879	0.458	0.789	0.504

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

C.1.6 Intermediate input market power

Lamp oil prices

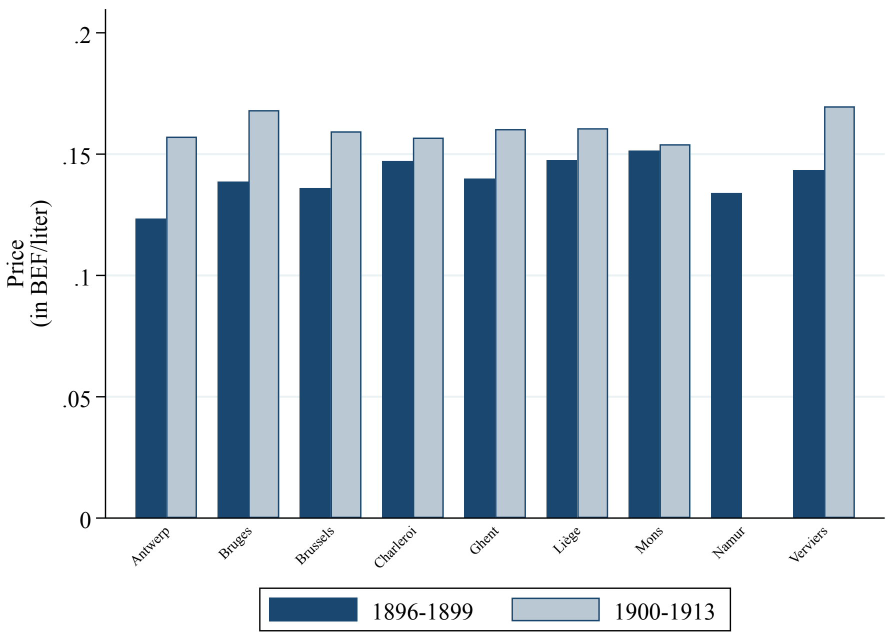
Our identification approach required exogenous intermediate input prices. We corroborate this assumption with further historical evidence. To do so, we collected monthly prices for *pétroleum* (lamp oil). Lamp oil was chosen because of data availability reasons, as well as its homogeneity allowing for straightforward regional comparison.[IX] This exercise results in a panel data set that covers all major urban and industrial centers in Belgium for the period 1896 to 1913.[X] As shown in Figure C.2, we find

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

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

little regional variation in the prices of this input, both within mining areas (such as between Mons, in the west, and Liège, in the east) and across mining and non-mining centers (such as Bruges, Brussels, and Ghent). This lack of price variation could either imply a very competitive or a collusive market. After all, limited wage heterogeneity within labor markets was also used to motivate our labor supply model. However, the key difference is the size of the market. Lamp oil was used in both mining and non-mining regions, and prices are homogeneous at the national, not just the local level. Even under Cournot competition, lamp oil price markdowns would be close to zero because the lamp oil market shares of coal firms would be close to zero.

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



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

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

The evidence on lamp oil prices underlines that at least for one industrial input, Belgian markets were well-integrated, and intermediate input prices were probably exogenous to individual coal firms. One caveat in this analysis is that the quantitative importance of lamp oil as a cost share of intermediate input expenditure was likely very small. We cannot compute this cost share directly as the data by the *Administration des Mines* does not allow us to observe the cost share of lamp oil in materials. Moreover, the financial records in the company archives which we consulted in the state archives of Liège do not have the level of detail needed to dissect intermediate inputs into individual products. However, we can estimate this cost share by making some assumptions on lamp oil usage rates. We know how many oil lamps were in use: in January 1907, 41.597 oil-based lights were in use to support the works of the 30.314 underground workers active at the mines in our sample, so about 1.4 lamps per worker (interestingly, electrical lamps were still not introduced by then - in contrast to the mines in the province of Hainaut). We can also make the modest assumption that mine workers used about 5.2 liters of lamp oil on a yearly basis.[XI] This allows us to estimate the yearly cost of lamp oil at mine level as: number of underground workers $\times 1.4 \times 5.2 \times$ lamp oil price per liter. Using yearly averages of the lamp oil price data we collected, we find an average firm-level lamp oil cost share of approximately 0.12% for the period of 1896 to 1913.

Revenue production function

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

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

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

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

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

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

$$\begin{cases} \mu_{ft}^m = \frac{\tilde{\beta}^m}{\frac{W_{ft}^m M_{ft}}{R_{ft}}} \\ \mu_{ft}^l = \frac{\tilde{\beta}^l}{\frac{W_{ft}^l L_{ft}}{R_{ft}}} \end{cases}$$

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

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

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

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

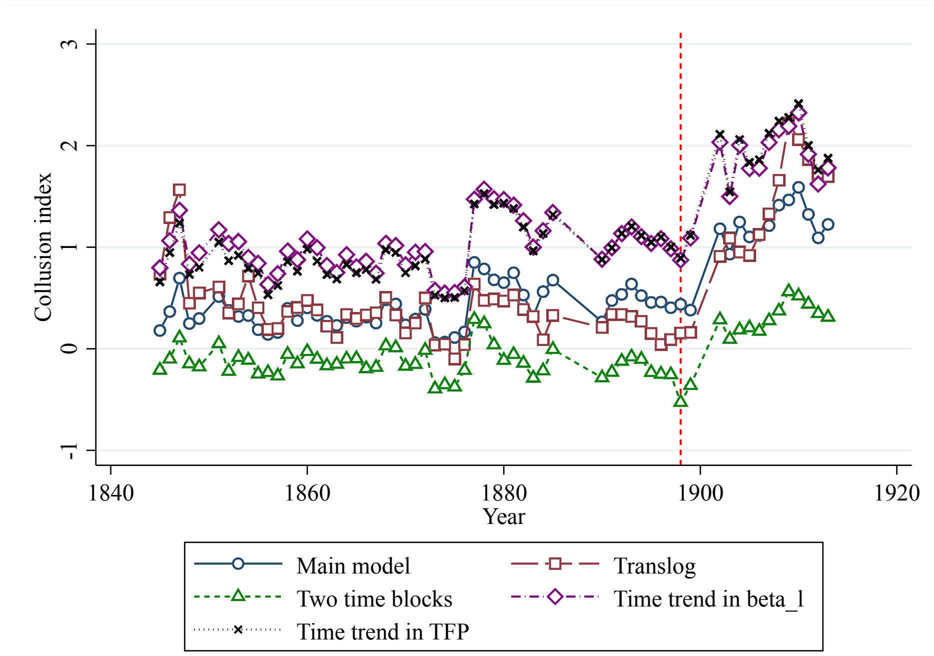
Panel B: Markups	Est.	S.E.	Est.	S.E.	Est.	S.E.
Average markdown	1.972	0.412	1.684	0.335	2.231	3.030
Average markup	.	.	1.820	0.412	0.649	0.686

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

C.1.7 First differences

As a robustness check, we set the serial correlation in TFP to one, $\rho = 1$, which implies that productivity is a random walk. Accordingly, we estimate the production function in first differences: we still rely on the GMM estimator outlined in the main text, but set the serial correlation to $\rho = 1$ rather than estimating it. The corresponding production function estimates are in the second column of Table C.5 and give higher output elasticities of labor and materials than in the main specification. The output elasticity of labor is even above unity, and returns to scale are estimated at 2.187, which we deem unrealistically high; it is hard to reconcile such a degree of increasing returns to scale with the relatively unconcentrated market structure observed in this industry. Moreover, a random walk process for productivity implies that productivity growth is fully unpredictable across firms. In most settings, including our baseline model, the serial correlation of productivity is estimated to be below one, which implies a stationary productivity process with some firms growing persistently, whereas others are not. On the other hand, the first-differenced model has a relatively low J-statistic, even compared to the full model in the main text. When using the first-differenced model to estimate collusion, as is shown in the black crosses in Figure C.4, the corresponding collusion estimates are nearly identical to those in the main specification where ρ was not fixed to be equal to one.

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



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

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

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

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

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

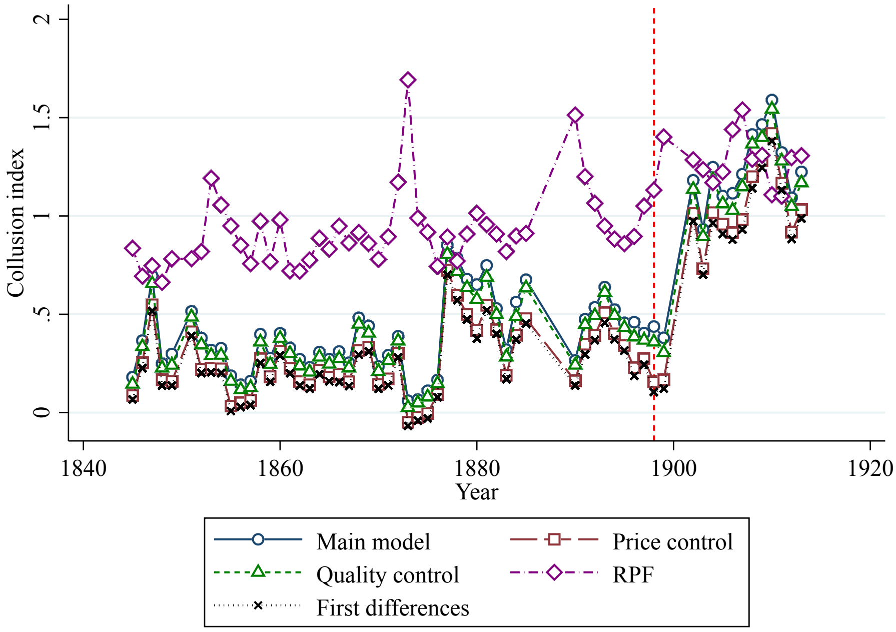
C.1.8 Cost shares approach

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

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

If we make an assumption about the returns to scale parameter ς, we can estimate bounds on the output elasticity of labor β^l as the markdown-weighted cost share using the non-collusive and fully collusive wage markdown values $\underline{\mu^l}$ and $\overline{\mu^l}$ from the labor

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



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

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

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

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

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

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

C.1.9 Serial correlation in estimated productivity shocks

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

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

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

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

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

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

Panel A: Serial correlation of productivity shocks in AR(1) model	Productivity shock	
	Est.	S.E.
Lagged productivity shock	-0.204	0.148
Observations	8779	
Panel B: Production function coefficients in AR(2) model	log(Output)	
	Est.	S.E.
log(Labor)	0.598	0.163
log(Materials)	0.201	0.111
log(Capital)	0.355	0.129
One-year TFP correlation	1.365	0.263
Two-year TFP correlation	-0.407	0.181
Observations	3571	

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

C.1.10 Extension to multi-product firms

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

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

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

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

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

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

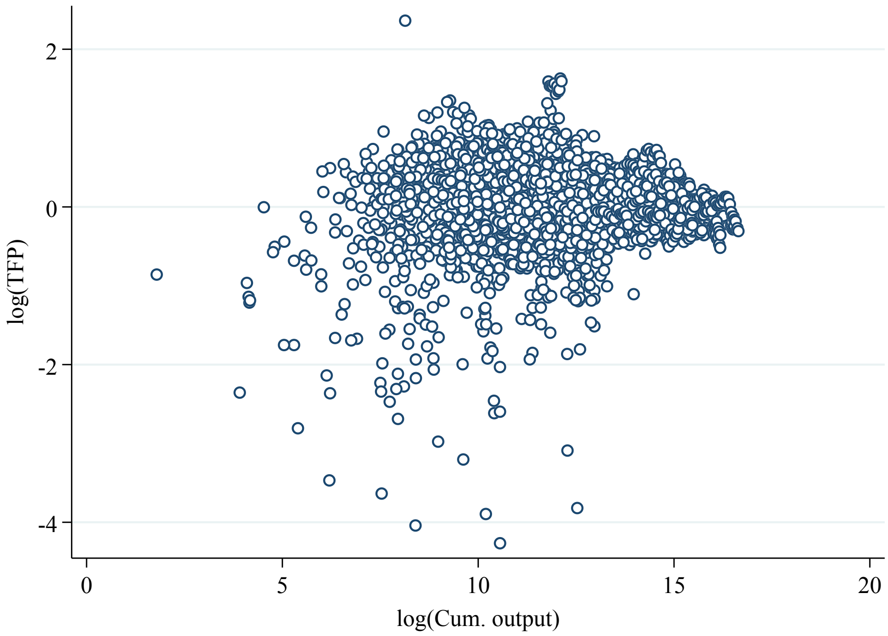
$$\mu^l_{fjt} \equiv \frac{\theta^l_{fjt} W^m_{fjt} M_{fjt}}{\theta^m_{fjt} W^m_{fjt} M_{fjt}} \tag{C.8}$$

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

C.1.11 Cost dynamics

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

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



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

C.1.12 Production coefficients with different IV selections

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

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

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

Furthermore, we re-estimate the production model while relying on shocks to

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

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

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

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

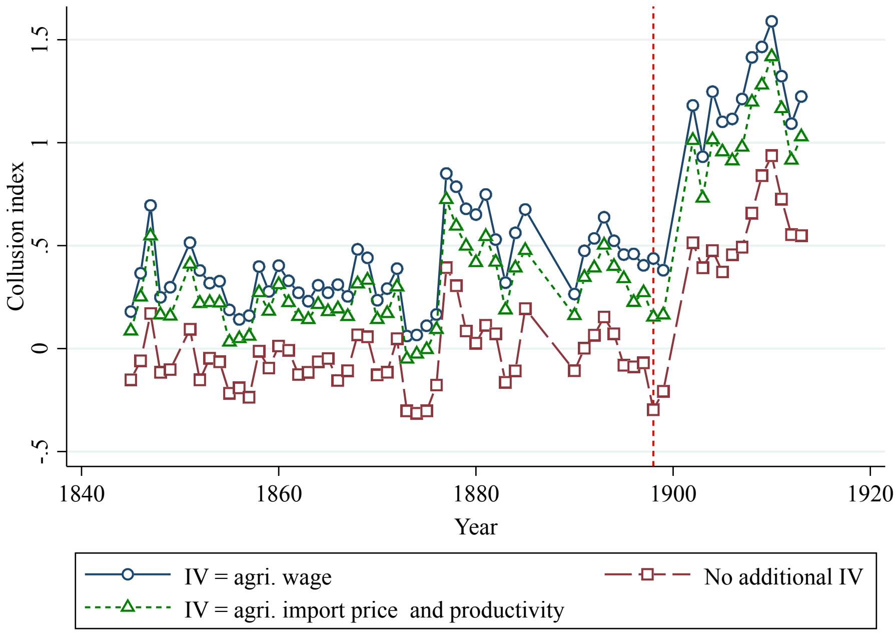
Belgian agricultural wages. We include two drivers. First, we compute a measure of agricultural productivity in Belgium by dividing an agricultural production index from Gadisseur (1979) by linearly-interpolated agricultural employment from Buyst (Forthcoming). This agricultural labor productivity series picks up both harvest shocks and the mechanization of the agricultural industry. Second, we collect data from the Belgian trade accounts, as adapted by Degrève (1982). We compute the log import price of four key agricultural products grown in Belgium, rye, wheat, oats, and barley, as defined as the logarithm of total import expenditure on these crops (in 1000 BEF) divided by the total import quantity (in 1000 kg).[XII] Belgian farmers faced increased international competition, notably from the U.S. (for an appraisal, see O'Rourke 1997; for a

[XII]Similarly, we also considered the prices of all products with under industry heading "agriculture and livestock production" (major group) in the *International Standard Industrial Classification of All Economic Activities* (ISIC revision 2). We did so by manually coding the trade data into the *Standard International Trade Classification* (SITC revision 2), which we converted into ISIC using the concordance table provided by Muendler (2009).

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

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

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



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

C.2 Labor supply: extensions and robustness

C.2.1 Wage variation and firm fixed effects

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

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

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

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

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

C.2.2 Test for employer differentiation

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

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

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

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

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

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

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

Notes: Robust standard errors are included.

C.2.3 Differentiated employers models

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The corresponding average wage markdown ratio is 2.6 for the linear worker utility model, 2.3 for the loglinear worker utility model, and 2.0 for the loglinear model with alternative wage. These wage markdowns are substantially above the markdowns found in the production model, and they are, in most years, even above the fully collusive markdown in the Cournot model. Figure C.7 plots the median ratio of the production markdown over the non-collusive lower markdown bound in the four specifications: the Cournot model and the Bertrand models with linear utility, loglinear utility, and loglinear utility with alternative wage. As was explained in the main text, the median wage markdown is twice the size of the non-collusive Cournot markdown, which points to wage collusion. In the linear utility Bertrand model, the production markdown is below the non-collusive lower bound until 1901, which cannot be reconciled with economic theory. We still notice an important increase in the production markdown relative to the non-collusive Bertrand markdown after the introduction of the cartel. For the loglinear utility model, the median markdown is below the non-collusive lower bound in almost every year. The production-based wage markdowns

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

are, hence, not in line with the Bertrand wage markdown bounds. This gives reason to reject the differentiated employers Bertrand model, under the assumption that the production-based markdowns are the true markdowns. Finally, for the loglinear model with alternative wage, the median markdown is also below the non-collusive lower bound for all years except in the 1850s and after 1900. Again, the relative markdown increase after the cartel's introduction still holds under this specification.

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

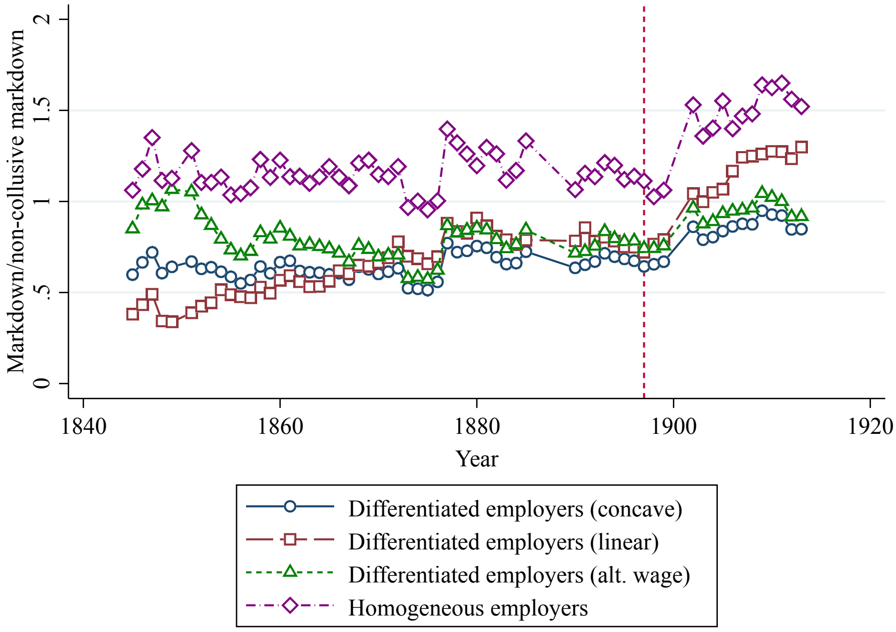
Panel A: Labor supply	Linear U.		Concave U.		Alt. wage	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
Wage coefficient, α	0.308	0.057	0.740	0.125	0.525	0.800
Outside option, b					0.641	2.124
Observations	4594		4593		4360	
Panel B: Markdown	Linear U.		Concave U.		Alt. wage	
	Average	Median	Average	Median	Average	Median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

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

C.2.4 Time-varying labor supply elasticity

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

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



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

$$w_{it}^l = \Psi_1^l l_{it} + \Psi_2^l l_{it} I(t < 1880) + \Psi_3^l I(t < 1880) + \nu_{it} \tag{C.13a}$$

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

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

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

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

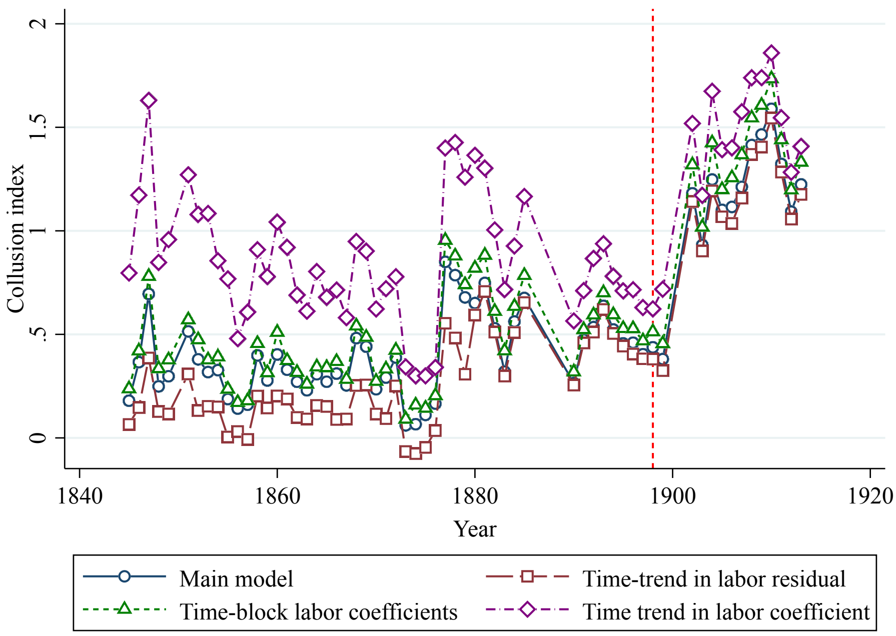
We present the resulting labor supply coefficients for these three specifications in Table C.12. The time block-specific labor supply model and the model with a time trend in the labor supply residual both imply a very similar evolution of employer collusion as the main specification, as can be seen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

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

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

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

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



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

C.2.5 Labor market definitions

In the main text, we defined labor markets at the municipality level. The expansion of the railroad and tramway network could threaten the validity of this market definition.

Figure D.6 in Appendix D.2 shows that the railroad network expanded mainly from the 1840s to the 1870s. By 1880, all villages in our data set were connected to the railroad network. Starting in the 1880s, a local tramway network was added, which increased commuting options for workers who lived far from the local train station.

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

Table C.13: **Markdown correlates**

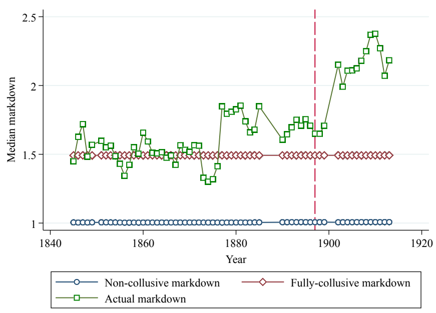
	log(Markdown)		log(Markdown)	
	Est.	S.E.	Est.	S.E.
1(Railroad)	-0.009	0.055	-0.001	0.049
1(Tramway)	-0.059	0.053	0.026	0.064
1(Urban)	0.066	0.044	0.000	0.000
One firm	0.069	0.220	0.091	0.138
Two firms	0.102	0.082	0.144	0.078
Three firms	0.032	0.082	0.049	0.068
Mine FE	No		Yes	
Year FE	Yes		Yes	
R-squared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

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

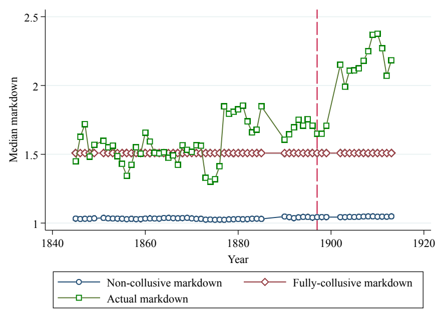
These estimates suggest that not taking into account changing commuting options when defining labor markets is not a key issue in the context of our paper. Nevertheless, it could be the case that we defined labor markets too narrowly or too broadly. In order to check the robustness of our results, we re-estimate the lower and upper markdown bounds under zero and full collusion at different market definitions. In Figure C.9, we define labor markets consecutively at the single-digit postal code level, which corresponds to provinces, and the two-, three-, and four-digit postal code levels. The four-digit postal code level corresponds to municipalities, which is the market definition in the baseline specification. At the one- and two-digit levels, labor markets are so wide that individual firms have close to zero market shares, which implies that the non-collusive markdown in the Cournot model is close to one: individual firms have no wage-setting power. Using these market definitions, firms were already fully colluding on the labor market prior to forming the cartel and were reaching a markdown above the collusive upper bound after the cartel. Contrary to this, defining labor markets at the three-digit level, which corresponds to groups of three to five municipalities, delivers very similar markdown bounds to those in the baseline specification.

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

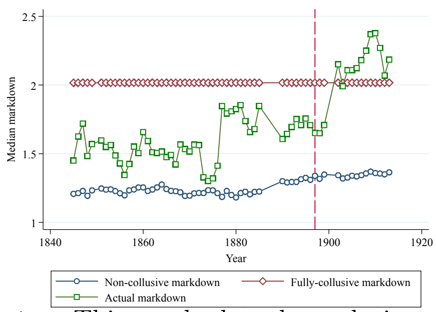
(a) **1-digit (Province) level**



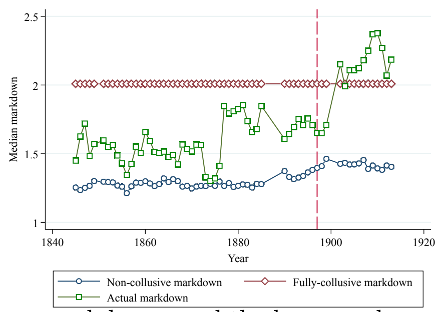
(b) **2-digit level**



(c) **3-digit level**



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



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

C.2.6 Different definition of the labor demand shock

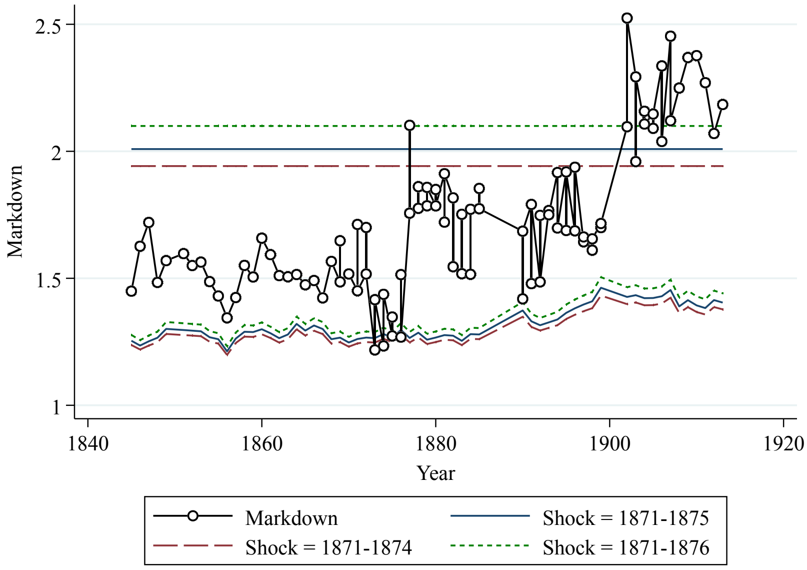
In the main text, we defined the labor demand shock due to the international coal price surge after the Franco-Prussian war as the period 1871-1875. This definition was done based on the price hike seen in Figure 2. As a robustness check, we re-define this labor demand shock as the period 1871-1874 and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

C.2.7 Different instrument selection

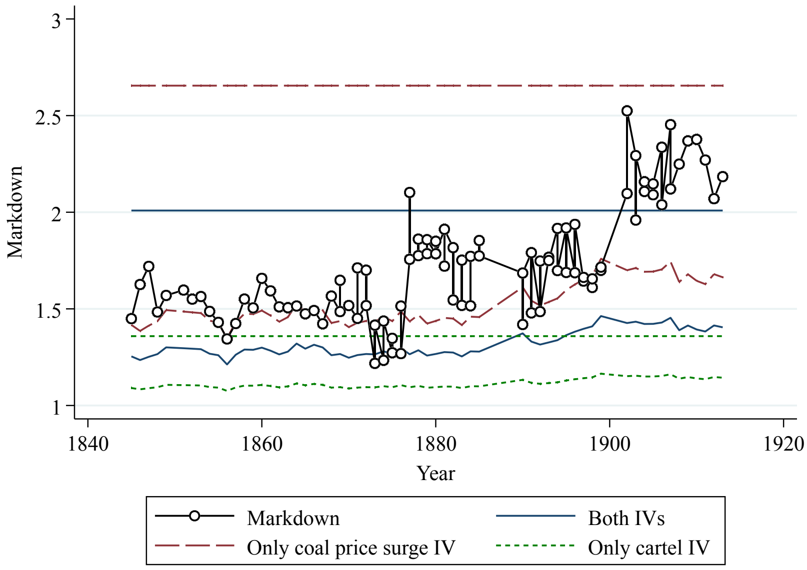
The overidentification test for the labor supply model in the main text rejected overidentifying restrictions. As a robustness check, we re-estimate the model using only the post-war coal price hike and the cartel introduction, interacted with cartel membership, as instruments. The corresponding markdown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

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

(a) **Alternative labor demand definition**



(b) **Alternative IV selection**



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

C.3 Other robustness checks

C.3.1 Compensating differentials

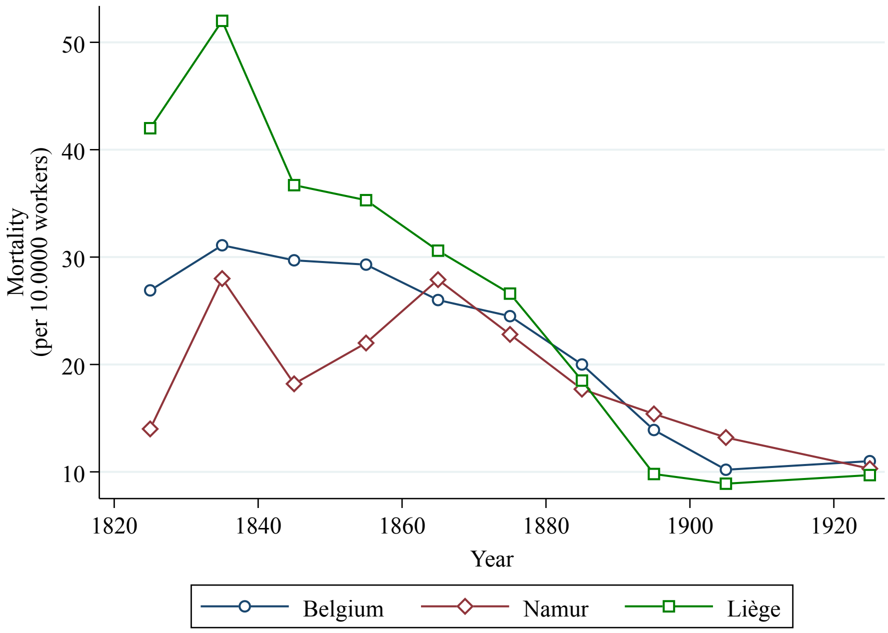
Another possible driver of the long-run evolution of markdowns are changes in compensating differentials due to changes in mining risk. Such compensating differentials are embedded in the amenity terms a_{ft} in the differentiated employers model of Appendix C.2.3. Still, we note that the nature of work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

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

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

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

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



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

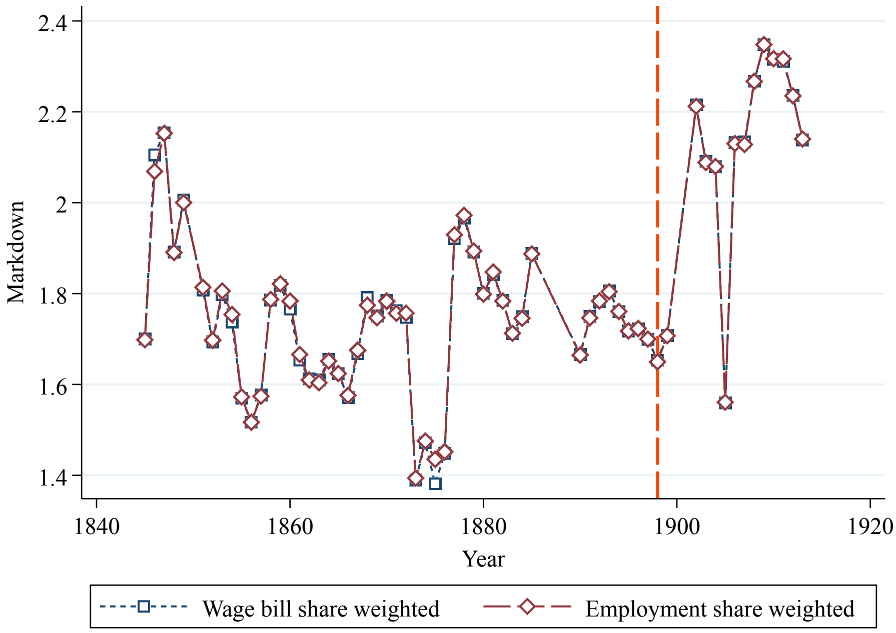
Source: Coal mining accident data and employment are from the published accounts of the *Administration des Mines*, as cited in Leboutte (1991).

C.3.2 Aggregation

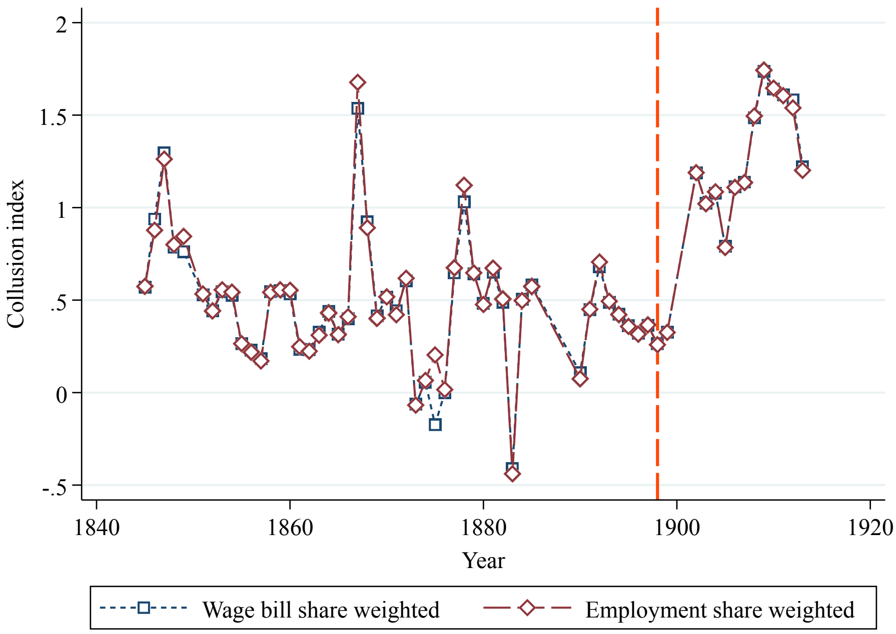
In the main text, we aggregate markdowns and collusion indices by taking employment share-weighted averages. When weighting by wage bill shares, we obtain very similar results. Figure C.12 shows the aggregated markdowns using weights based on wage bill shares and employment shares. Figure C.12b does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

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

(a) **Wage markdown**



(b) **Collusion estimates**



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

C.3.3 Political changes and democratization

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

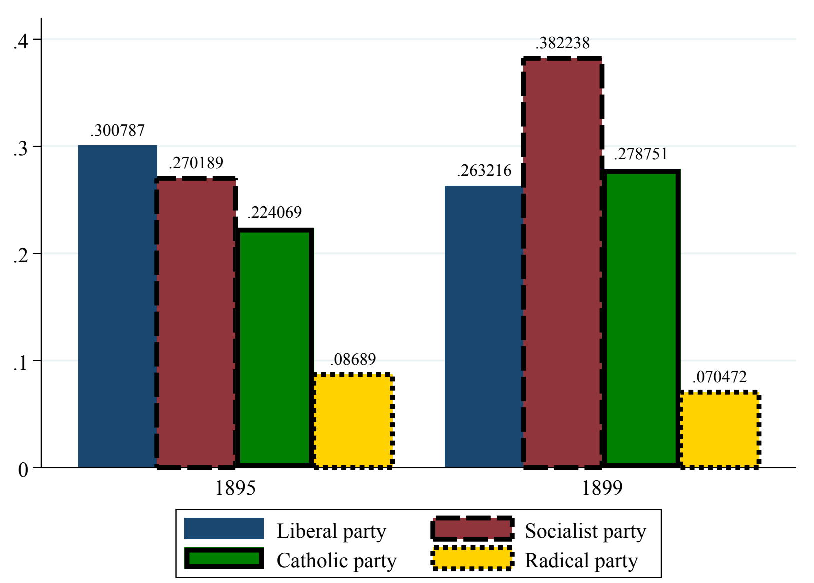
Figure C.13a documents the voter shares of the first two elections at the community level with universal suffrage, showcasing the popularity of the new POB within the Liège and Namur industrial areas. The question is now whether this growing political emancipation of the working class translated into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

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

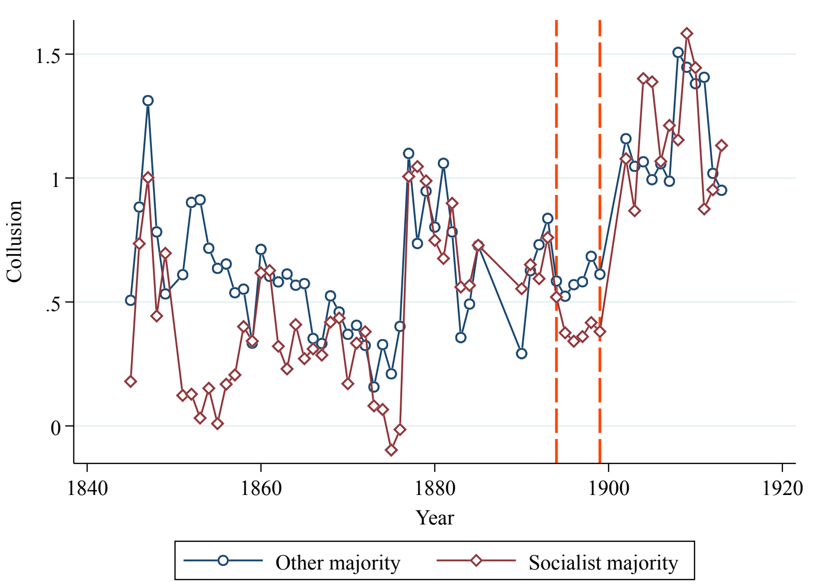
[XVI] An important example is the 1891 encyclical of Pope Leo XIII, *Rerum Novarum* or *Rights and Duties of Capital and Labor*, which had a revolutionary impact on the Belgian Christian party. In this letter, the Catholic leader also expressed his condemnation of what we would now call monopsony: "doubtless,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

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

(a) **Evolution of voter shares**



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



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

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

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

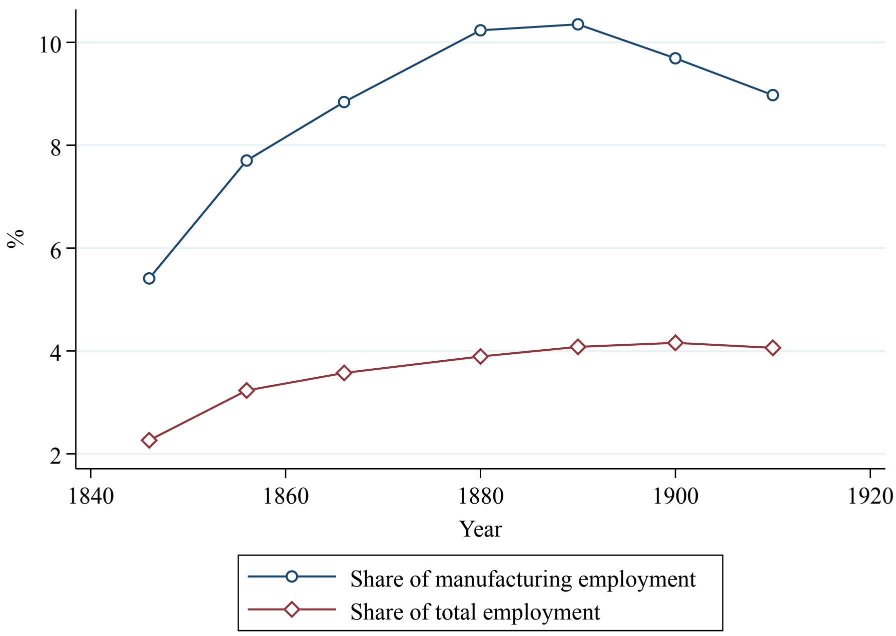
[XVII] Uncoincidentially, it was also only in this era that trade unions would become legitimate political institutions as well as recognized partners in the wage bargaining process (see Section 2.3).

D Additional empirical results and background data

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

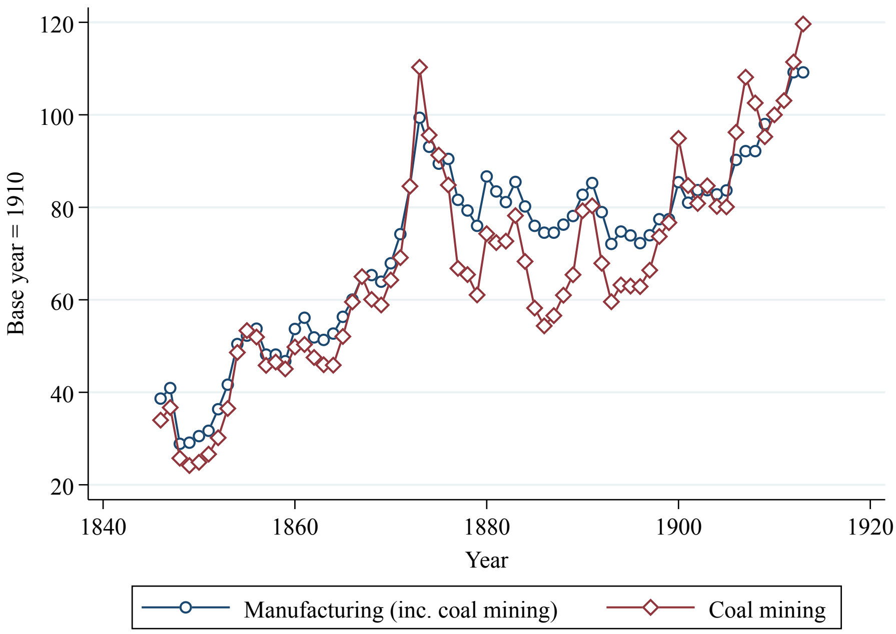
Figure D.1 illustrates the strong importance of coal mining in the Belgian industry throughout the 19th century from an employment perspective. Further disaggregation of the data in Belgian population censuses to the province level indicates that in 1846, about 5% and 4% of male and female workers of the provinces of Liège and Namur, respectively, worked in coal mining. By 1910, this share increased to 10%, while it remained relatively constant in Namur. Overall, these data paint a picture of the coal industry as a prominent employer, both at the national and regional level. Moreover, Figure D.2 underlines how wage developments in coal mining are indicative of the evolution in the industry overall.

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



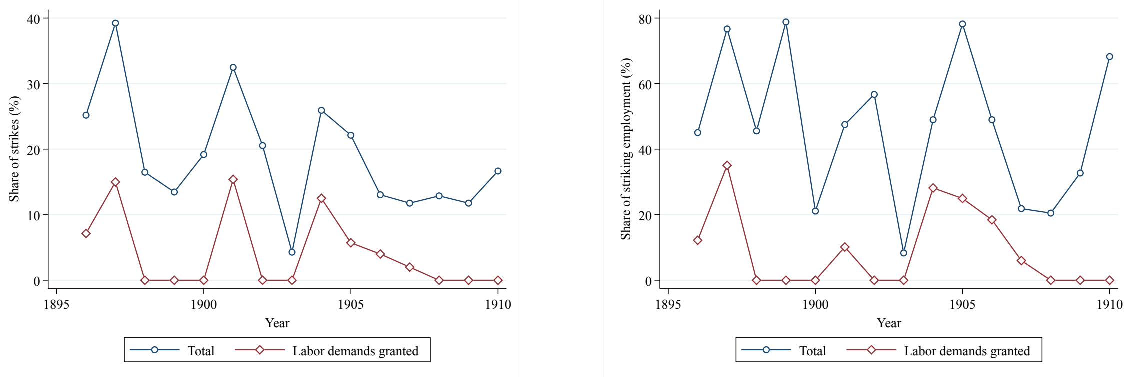
Source: Coal mining employment is from the published accounts of the *Administration des Mines*, as cited in Gadisseur (1979). Manufacturing and total employment are based on Buyst (Forthcoming).

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



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

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

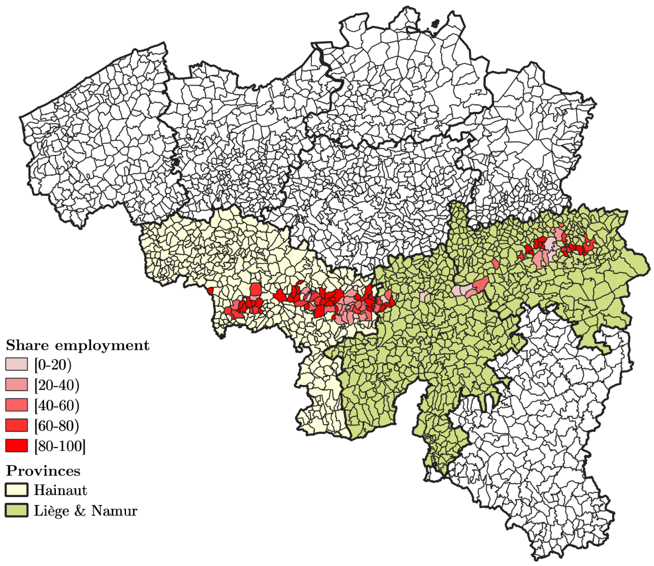


(a) Number of strikes (b) Number of strikers involved

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

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

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



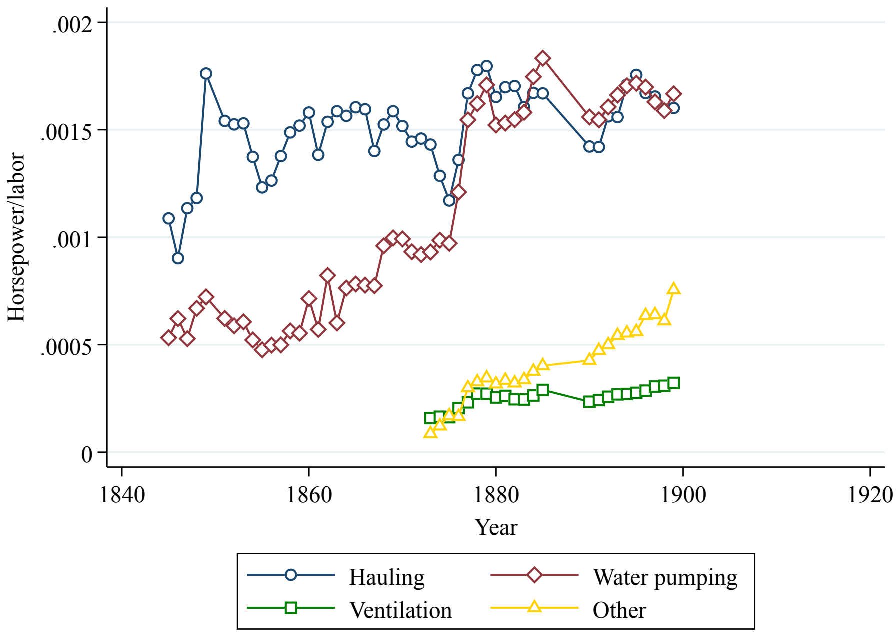
Notes: Historical community borders of 1890.

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

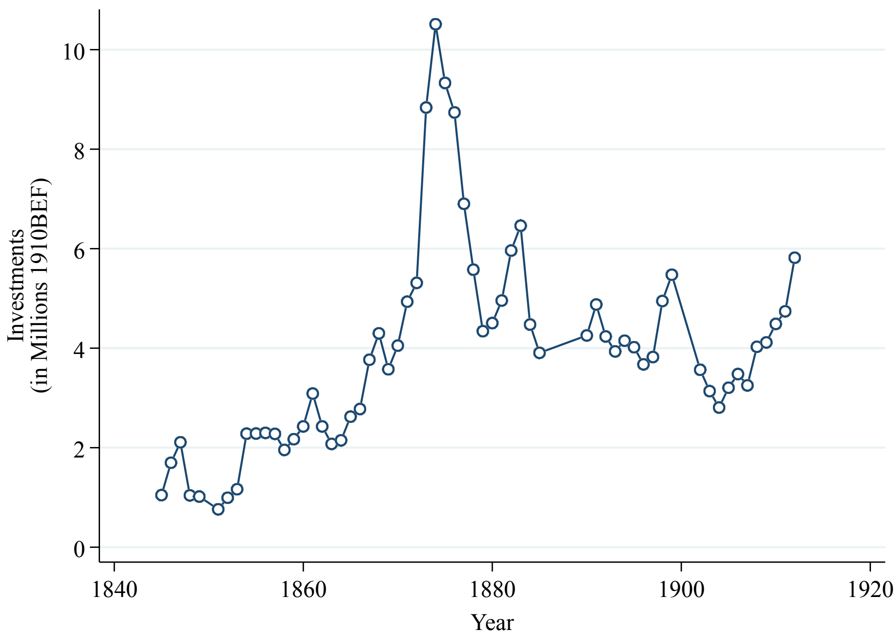
D.2 The Liège and Namur-based coal industry in the long 19^{th} century

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

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



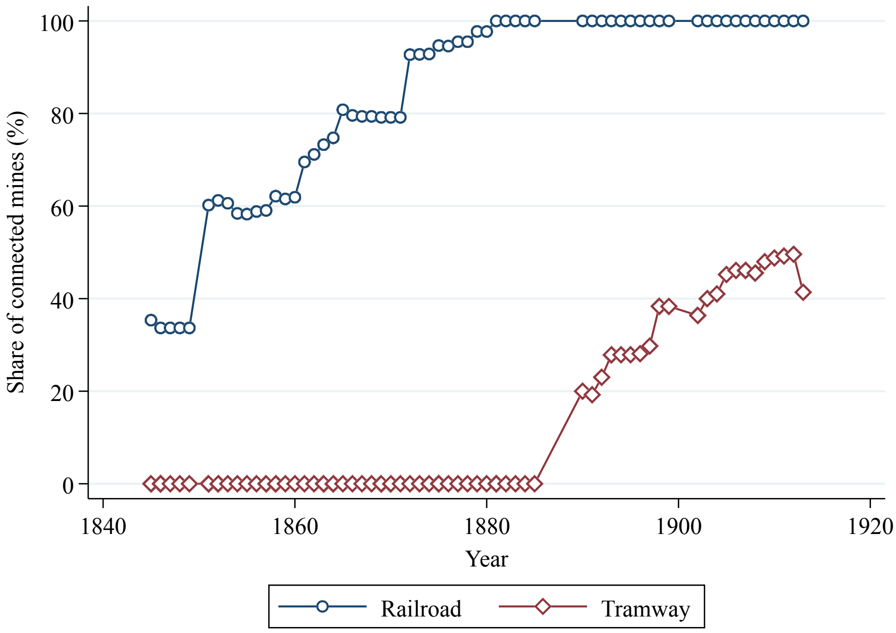
(b) **Total investment by the Liège and Namur coal firms, 1845-1913**



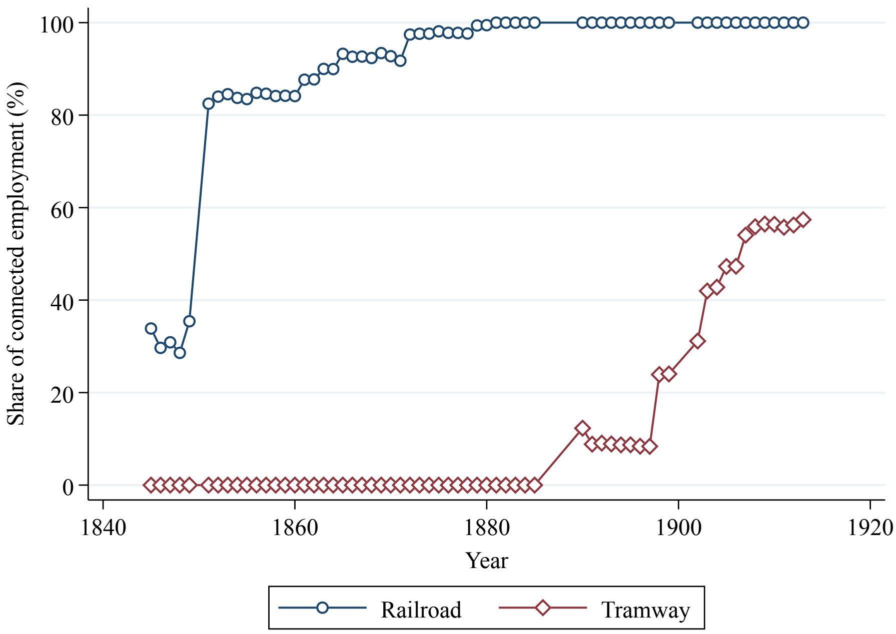
Notes: Figure (a) plots the evolution of horsepower per worker-day for the four technology classes in our dataset. Figure (b) plots the evolution of total capital investment of coal mines in the sample.

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

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



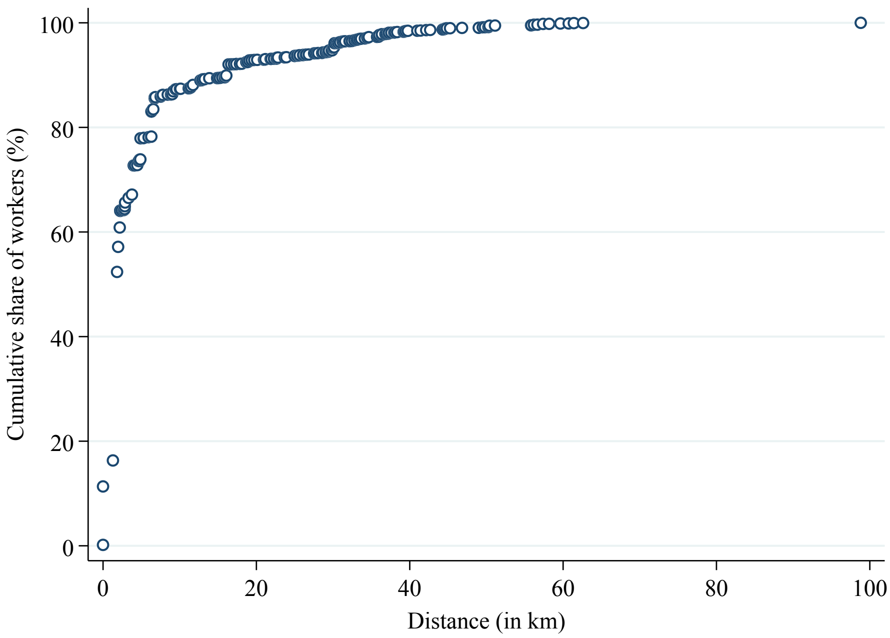
(b) **Share of connected employment**



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

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

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



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

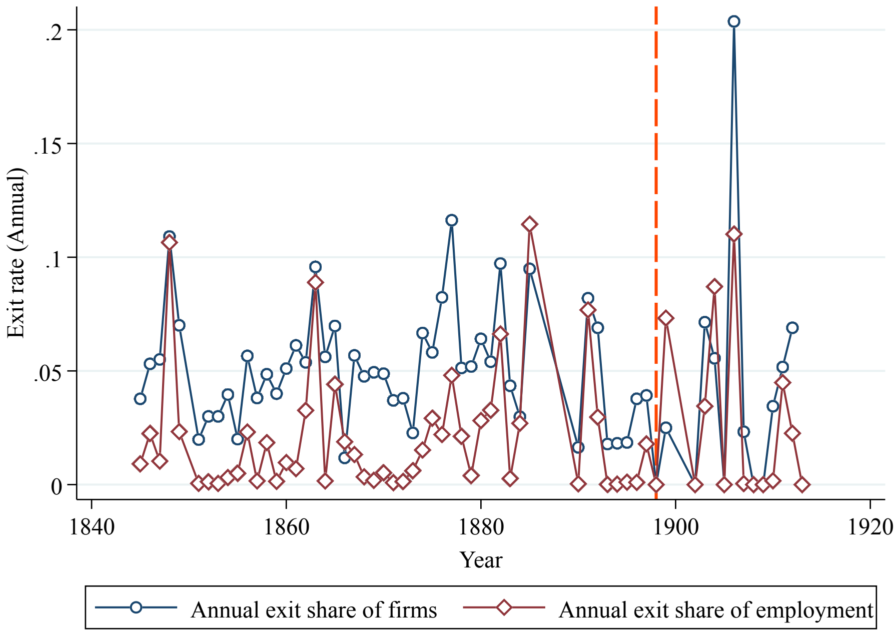
D.3 Endogenous exit

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

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

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

(a) **Annual exit rates**



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

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

Methodology

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

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

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

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

Results

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

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

The first column in Panel B of Table D.1 reports the average change in the firm exit rate when moving from the cartel to Cournot equilibrium, using the model that

Table D.1: **Endogenous exit**

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

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

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

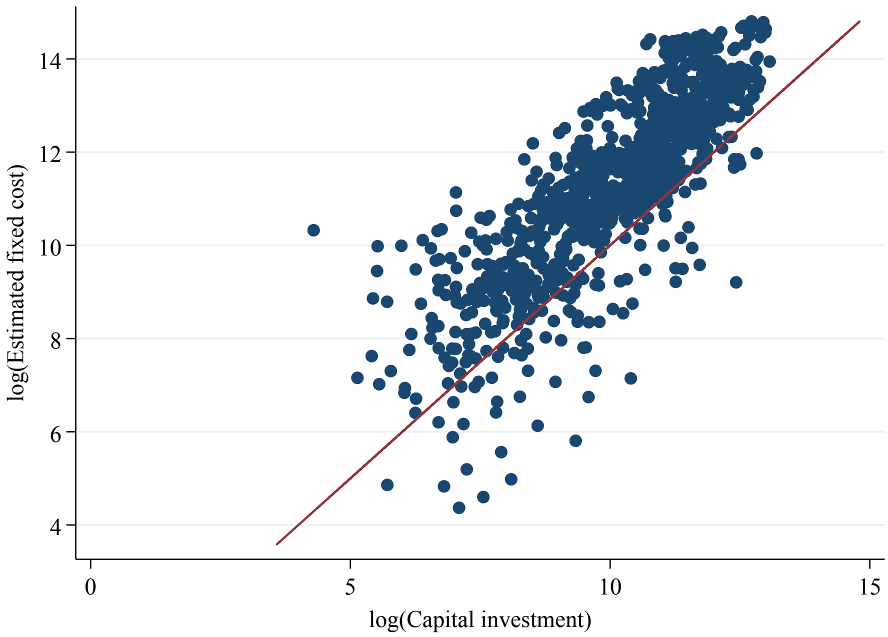
The large change in the exit rate for both the Cournot and pre-1898 conduct counterfactuals is logical: under the exogenous price model, the only source of profits is the wage markdown. Given that labor markets are not very concentrated, Cournot markdowns are low. Hence, variable profits fall considerably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

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

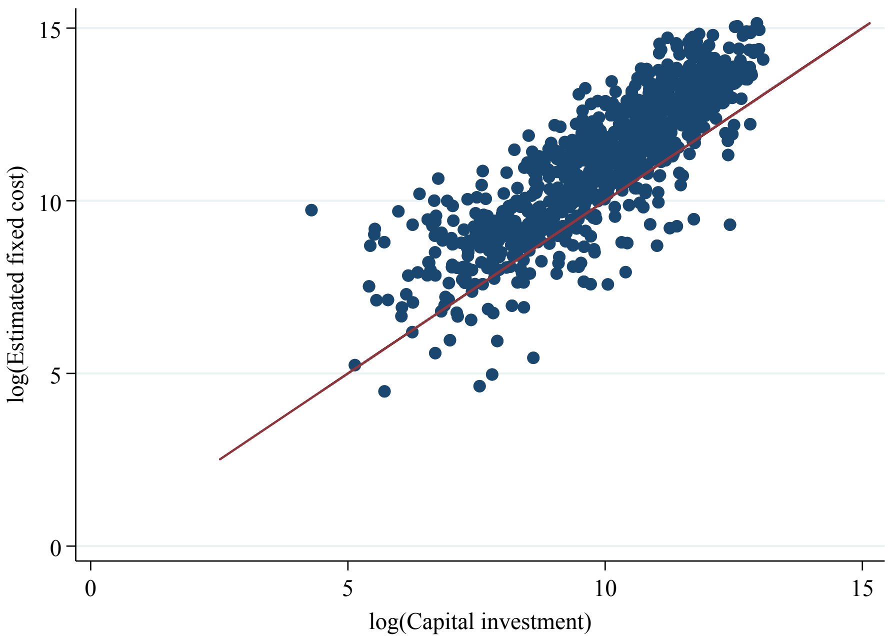
In sum, we find exit rates would be higher in the absence of the cartel, although the magnitude of this effect is relatively small under the assumption that firms had some market power downstream. However, given that the baseline exit rate was small, the additional exit in the absence of the cartel would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

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

(a) **Exogenous price model**



(b) **Endogenous price model**



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

D.4 Markups and the cartel

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

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

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

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

D.5 Coal demand estimates

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

Table D.3: **Coal demand**

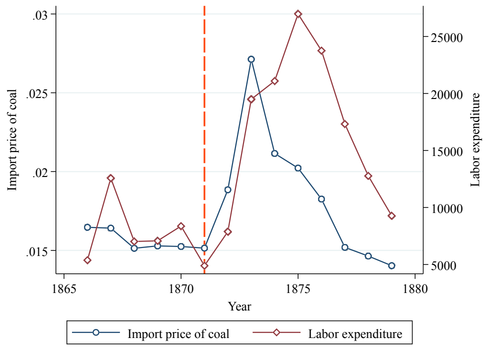
	log(Price)		log(Price)	
	Est.	S.E.	Est.	S.E.
log(Output)	0.073	0.004	-0.383	0.116
Method	OLS		IV	
First-stage F-statistic			22.7	
Observations	1913		1913	

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

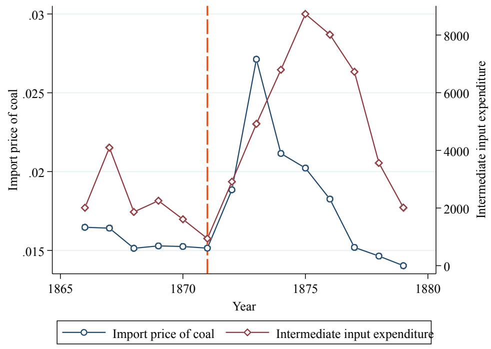
D.6 Other results

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

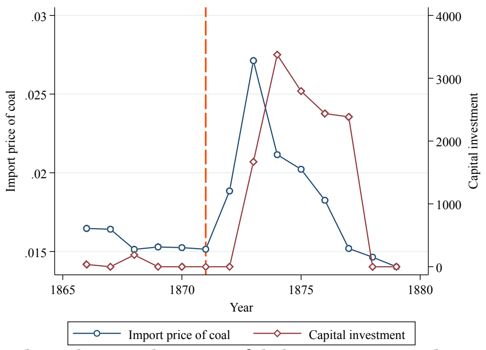
(a) **Labor expenditure**



(b) **Intermediate input expenditure**



(c) **Capital investment**



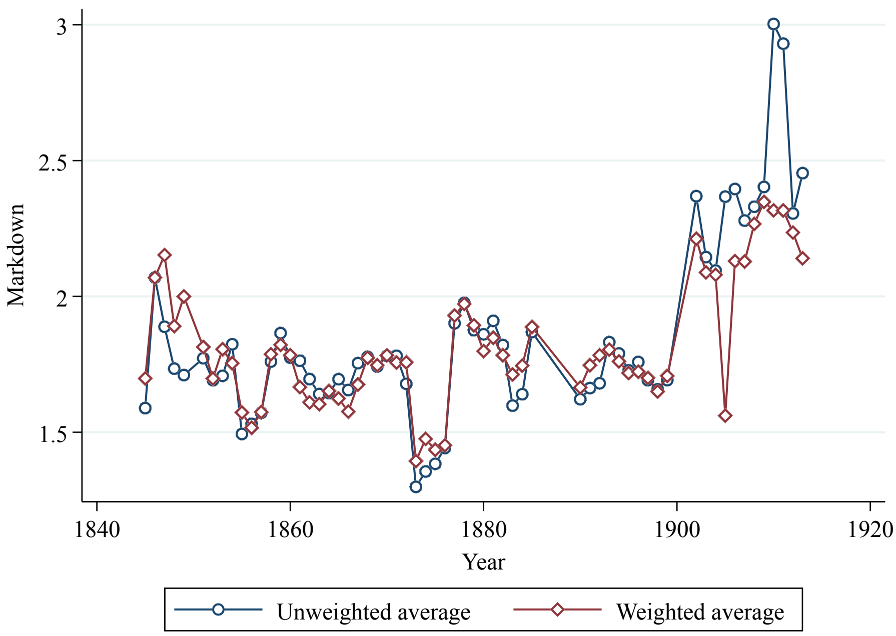
Notes: These figures plot the evolution of labor, intermediate input, and capital expenditure after the 1871 international coal price shock. The dashed vertical lines indicate the coal demand shock. The import price of coal is also plotted.

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

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

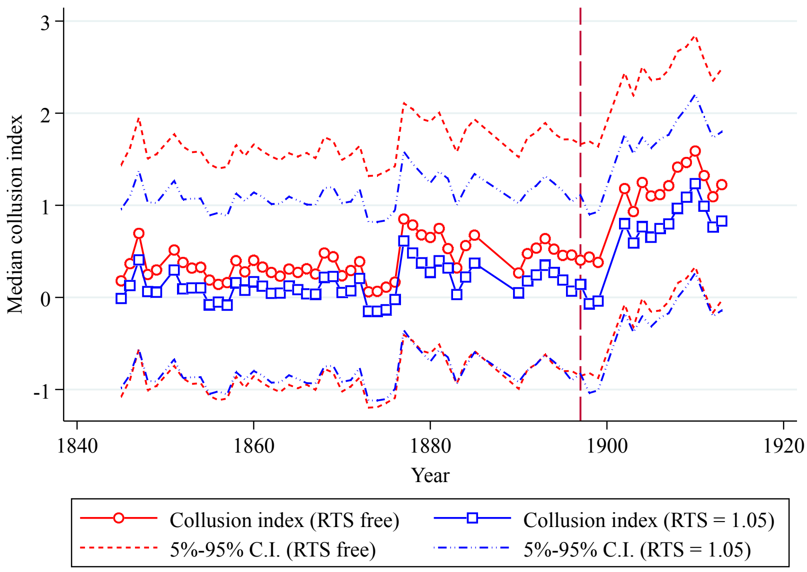
Notes: This table reports the estimates of a regression of the yearly change in the log total number of workers in the Liège and Namur coal basin on the yearly change in log agricultural wages in Belgium, between 1845 and 1913. Robust standard errors are included.

Figure D.11: **Markdown reallocation**



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

Figure D.12: **Employer collusion index: 5-95% confidence interval**



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

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