Expansion, Depression and Collusion: The Belgian Coal Industry, 1901-1945*

Gil Montant
CRISS - Université Polytechnique Hauts-de-France

Abstract

In the first half of the twentieth century a variety of factors – stagnant extraction processes, fierce competition from abroad, less favourable geological endowment, unstable demand during the interwar years – led Belgian coal producers to unify in order to preserve their production capacities. This paper takes the presence of massive coal imports in the Belgian market into account by using a three-equation theoretical model derived from industrial economics to assess the impact of the economic cycle on Belgian coal producers' market power within their domestic market. The results indicate that collusive strategies had a significant impact on the relationship between the economic cycle and the price-cost margin in the Belgian coal industry. In particular, the estimates do not contradict the findings of Haltiwanger and Harrington (1991).

1. Introduction

Motivation of the paper

Firms that develop in a market are always tempted to reduce the degree of competition. All else being equal, the less stringent is competition, the higher will be both the market price and the level of profits. This characteristic is even more important in industries that face high fixed costs, which make it even more crucial

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to prevent destructive competition. Mining in general and the coal industry in particular, owing to geological and economic constraints, are especially concerned by this potential threat.

The presence of high fixed costs implies a specific constraint on firms' ability to continue working. In mining, moreover, underground veins need to be regularly exploited, if only to pump water out of underground galleries. These structural elements make mining companies especially prone to engage in harsh competition when their individual demand follows a declining trend. This feature is reinforced when there is intense competition from abroad. In such a setting, collusive strategies play a crucial role as a tool to avert price wars and preserve the mining industry's extractive capacity.

These various features are well represented in the case of the Belgian coal industry in the first half of the twentieth century. Historical records indicate that Belgian collieries pursued collusive strategies during several years of that period. Moreover, the Belgian coal industry faced unstable economic conditions, notably in the 1930s. The availability of abundant and original data allows us to empirically test the impact of the business cycle on firms' ability to sustain some strategies of collusion. Finally, to the best of our knowledge no previous empirical work has been published on this specific question, which deserves analysis.

The analysis developed here addresses a core issue in the field of industrial economics, namely the ability of firms in a market to sustain collusion within an unstable economic environment (economic upturn/economic downturn). The question was studied by Haltiwanger and Harrington (1991), who analysed the impact of the business cycle on the ability of firms to collude on price within a deterministic demand cycle, finding that the degree of collusion tends to anticipate the business cycle.

The present article's methodological contribution consists in the implementation of a new approach to study the impact of the business cycle on firms' ability to sustain collusive strategies. In particular, the method introduces an explicit distinction between the level of demand and its evolution, thereby enriching the approach taken by Rosenbaum and Sukharomana (2001), who only consider the economic trend without taking into account the level of demand in the industry. The introduction of a second dimension (the level of the demand) increases the number of cases to be considered from just two (increasing demand vs decreasing demand) to four (downward high demand, downward low demand, upward low demand and upward high demand).

This analysis has two main objectives. First, from a historical point of view, it aims to assess the ability of Belgian collieries to react to collusive strategies developed by foreign competitors such as coal producers located in the UK, the French collieries and above all the German coal producers of Rhineland-Westphalia. Second, from a theoretical point of view, it aims to analyse empirically the impact of the economic cycle on the collusive price strategies in the Belgian coal industry, using the model derived by Haltiwanger and Harrington (1991). The focus on the coal industry stems from the fact that it is specifically prone to collusion owing to several distinct features, detailed in the next section.

Literature review

A body of studies have examined collusion in the coal industry. Fleming (2000) analysed the case of the Australian collieries, Hausman (1984) developed an econometric analysis of market power in the UK during the eighteenth and nineteenth centuries, Peters (1989) focused on the German collieries from 1893 to 1913 and Heaulme (1948) on collusion in the Northern coalfields of France. Collusive strategies in the Belgian coal industry have not been extensively analysed; the literature on the subject is quite thin (Coppé 1940; Kurgan-Van Hentenryk and Puissant 1990). In particular, the problem's quantitative dimension does not appear to have been the subject of previous studies.

The theoretical results of Haltiwanger and Harrington (1991) have been tested with data gathered on various industries: the rayon industry in the 1930s (Gallet and Schroeter, 1995), the U.S. Portland cement industry in the period 1974-1989 (Rosenbaum and Sukharomana, 2001) and the Northern French coal industry in the interwar period (Montant, 2009). However, these studies suffer from a significant shortcoming: even if they explicitly incorporate the direction of the trend of demand, they fail to consider the level of demand, whereas the theories derived by Haltiwanger and Harrington (1991) and Knittel and Lepore (2010) explicitly differentiate the direction of the demand from its level.

The plan of this article is as follows. Section 2 describes the historical context, highlighting the chief characteristics of the case being examined. Section 3 summarises the economic literature on the impact of economic fluctuations on collusive strategies and then details the construction of the model. Section 4 presents the econometric results and their interpretations. Section 5 summarises the main findings and suggests possibilities for future research to extend them.

2. The Belgian coal industry in the first half of the twentieth century

The structure of the coal market and its evolution in the period 1901-1945

During the second half of the nineteenth century, many mining concessions were merged in order to improve their profitability (Leboutte, 1997, p. 184). The coal firms were grouped under the supervision of the Société Générale and the Banque de Belgique and the number of collieries decreased from 257 in 1839 to 125 in 1913 (Leboutte et al., 1998, p. 36). The period from the end of the nineteenth century to the beginning of WW1 was favourable for the Belgian coal industry.

In 1917, a new coalfield in northern Belgium, sometimes known as the Campine coalfield (and also as the Limbourg coalfield), began to be exploited, significantly increasing Belgian coal production, not least with the objective of reducing the country's dependence on foreign producers.[1] In this new coalfield, the number of collieries was,

[1] Belgian coal production was lower than the sum of domestic demand plus exports (see Figure 1).

from the start, limited to seven large firms (Leboutte, 1997, p. 185). According to Pirenne (1928, p. 123) coal mining was never interrupted during the Great War and the exploitation of the new Campine coalfield never ceased. After the war, the Belgian coal industry comprised two coalfields, one in the north and one in the south. The northern coal basin, which comprised the Campine collieries, was the newer of the two. The southern coalfield was composed of five districts – Mons, Charleroi, Liège, Centre and Namur – all of which had been worked since the beginning of the nineteenth century (Leboutte et al., 1998, p. 47). During the interwar period, the importance of the Campine collieries continued to grow relative to the southern coalfields, thanks to better geological endowments.

The Belgian coal industry versus foreign competition

In many ways, Belgian coalfields were at a disadvantage compared with their principal foreign competitors. They had less favourable geological conditions: the average quality of the coal seams was poorer than that of foreign coalfields located fairly close by. Moreover, Belgian coal seams were generally thinner than in most of the foreign competitors' coalfields (Michotte, 1929, p. 58, and Baudhuin, 1946, p. 19). In addition, Belgian coal ore had a high methane content, which significantly increased the risk of underground explosions. The difficulties confronting Belgian collieries were not only structural but also strategic, because some important coal producers in Germany and France were organised in cartels.

Up to April 1925, the Treaty of Versailles limited competition from German exports, but thereafter the two countries returned to free competition. The German coal industry was thus in a position to exploit its many strategic advantages and reduce prices (Kurgan-van Hentenryk and Puissant, 1990, p. 238). Production costs in the Ruhr were lower than those in Belgian mines, putting German coal in a position to invade the Belgian market. Between the wars, Germany was the main coal exporter to Belgium, followed by the Netherlands and the United Kingdom. Coal export statistics show that France was the Belgian coal industry's most important foreign customer by far and its relative importance remained stable. Table 1 details the relative importance of Belgium's main foreign suppliers and of its leading foreign customers.

TABLE 1
Shares of Belgian coal imports and exports by country (1923-38)

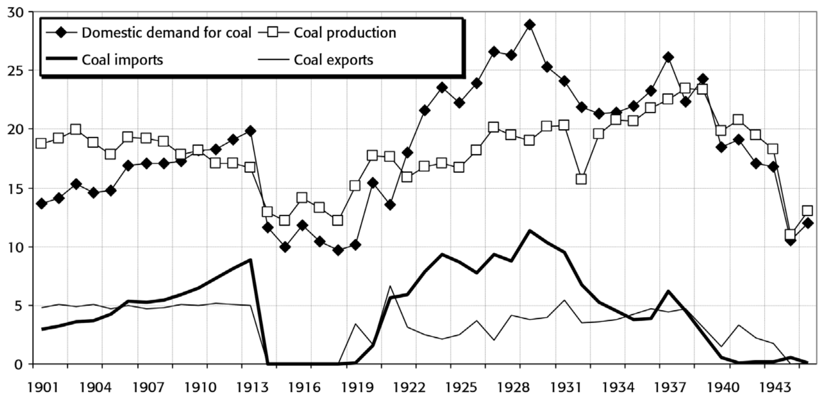
	1923	1924	1925	1926	1930	1931	1932	1933	1935	1936	1937	1938
Main exporters to Belgium												
Germany	18.7	48.6	46.6	53.6	42.6	46.2	49.3	49.3	59.7	62.4	60.5	54.0
Netherlands	7.7	9.9	15.2	23.4	17.7	20.9	18.5	17.5	17.7	20.2	16.9	17.7
United Kingdom	60.0	30.4	25.8	9.3	26.9	19.5	20.0	19.9	12.6	9.7	14.8	14.8
France	13.6	11.2	12.5	13.5	10.9	9.3	8.7	9.1	6.0	2.7	0.9	7.6
Poland	0.0	0.0	0.0	0.0	0.4	2.4	1.9	2.4	2.4	3.4	6.2	5.5
Main foreign customers												
France	79.0	77.7	79.4	60.6	78.7	72.5	78.3	80.0	69.3	62.9	77.4	74.6
Netherlands	11.8	13.8	8.9	7.4	7.3	8.3	9.0	9.6	8.2	7.1	7.6	10.9
Italy	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.3	9.5	16.7	4.5	2.4
Switzerland	7.9	7.5	5.2	3.6	2.4	2.0	2.6	2.1	1.2	0.9	1.5	1.7

Notes and sources: Percentages of total coal exports to Belgium and total coal exports from Belgium. Comparable detailed data are not available in *Annales des Mines de Belgique* prior to 1923. Sources: Data for 1923-26, *Annales des Mines de Belgique*; data for 1930-33, *Bulletin de l'Institut des Sciences Économiques*, vol. 5, 1933-1934, p. 346; data for 1935-36, *Bulletin de l'Institut des Sciences Économiques*, no. 2, February 1937, p 149; data for 1937-38, *Bulletin de l'Institut de Recherches Économiques*, no. 2, February 1939, p. 158.

In spite of these significant structural and strategic difficulties, Belgian coal mines enjoyed two advantages in their domestic market that mitigated the picture painted above. First, almost 65% of total production was transported by rail (Coppé, 1940, p. 249). Foreign producers' advantage of higher labour productivity was more than offset by rail transport costs, although this was not the case when coal was shipped by water. Second, Belgian sales costs were lower than their foreign competitors'. These two factors made Belgian mines leaders in their domestic market, although their position was threatened by the strength of foreign coal producers, especially from the Rhenish-Westphalian region.

Over the period as a whole, domestic demand for coal and coal imports evolved in parallel. They trended upward between 1901 and 1913, then fell drastically throughout the First World War. During the 1920s both moved upward until 1929. During the thirties and WW2, the general trend was negative, except in 1937-1938. A parallel can also be drawn between the coal production and coal exports series. Both were mostly stable in 1901-1913 and showed a significant fall during WW1. Both series then trended upward until 1939. The sudden drop in production in 1932 was due to strikes that occurred between July and September against wage cuts (Meerten, 2003, p. 209). During WW2 both series recorded a significant decline. The evolution of domestic demand, production, imports and exports are shown in Figure 1.

FIGURE 1
Evolution of the Belgian coal market, 1901-1945



Notes and sources: The vertical axis indicates quantities of coal (in millions of tons). Sources are detailed in Appendices A.3 and A.4.

The importance of collusion in the mining sector

The collusive strategies in the coal industry played a strategic role because of several structural factors. First of all, the production cycle was characterised by a high degree of inertia, creating recurring storage problems for coal companies. This problem was exacerbated by the decline in the quality of the coal stored for long periods and the consequent fall in its price. Moreover, any significant interruption of the production cycle in a coal mine implied huge costs to restart extraction. This made it crucial for collieries to maintain a regular level of coal extraction. In the face of a sharp reduction in demand, firms therefore had a very strong incentive to cut prices so as to preserve sales volumes, even if they were in collusion. This explains why coal producers were inclined to initiate price wars when demand was falling. In retrospect, the creation of a cartel appears a rational solution designed by public and private actors to prevent price wars during episodes of slack demand. The proper functioning of the cartel in the coal industry was therefore absolutely essential to preserve the industry's production capacity.

Cooperation among Belgian coal producers

There had already been several cases of collusion in the Belgian coal industry in the last quarter of the nineteenth century, but those cartels exercised control over only a limited part of the domestic market (Kurgan-van Hentenryk and Puissant, 1990, pp. 206-208; Murray and Silvestre, 2020, p. 13). Apart from these local experiences, no significant collusive structure existed in the domestic coal industry. This suggests that the Belgian coal market was mainly driven by competitive forces up to the end of the 1920s (Michotte, 1929, p. 60).

During the German occupation, the occupying power had established a Central Coal Office to which all Belgian mines had to sell their coal ore. About half of the coal produced was sold in the domestic market, the rest being used by the German forces (i.e. army, military railroads) or exported to nearby neutral states (Liberman, 1996, p. 75).[2]

[2] The maintenance of the Belgian coal industry's activity during WW1 justifies including this period in the analysis.

In January 1928, the Comptoir Belge des Charbons Industriels was established, although the collieries did not sign a general agreement until 1929 (Kurgan-van Hentenryk and Puissant, 1990, p. 240). Since the turn of the century, Belgian coal imports had risen significantly, growing three-fold in 1901-1913 alone.[3] In the face of such intense competition, collusion was the best solution. More specifically, the creation of the new cartel was a response to the German collieries' dumping strategy (*Annales des mines*, 13ème série, tome XI, 1937, p. 385; Heaulme, 1948, p. 314), and it had strong support from the banking sector (Hogg, 1986, p. 87). However, the Comptoir Belge des Charbons was not a universal agreement because the Liège coal district, accounting for almost 30% of Belgian coal output, was not part of it.[4]

The economic depression led to intensified competition in the Belgian coal market during 1933-1934. Extensive powers voted to the government in July 1934 enabled the Minister of Economic Affairs to set up a compulsory coal cartel in December 1934 (Kurgan-van Hentenryk and Puissant, 1990, p. 242),[5] forcing Belgian coal companies to strengthen their cooperative links. In January 1935, the Office National des Charbons (ONC) was established and all Belgian coal producers had to join it. Yet, despite government pressure to cooperate, such a cartel could only be effective if Belgian collieries were consolidated, and this was a difficult challenge. Consolidation reduced the number of collieries, facilitating a cooperative agreement in Belgian mining. In May 1928, tax concessions were introduced to encourage smaller collieries to amalgamate and thus foster rationalisation in the industry (Hogg, 1986, p. 86). In spite of successive waves of mergers until the end of the 1920s, Belgian collieries

[3] These results are based on data from *Annales des Mines de Belgique* and *Annales des Mines*. See Appendix A.4.
[4] According to R. L. Hogg (1986, p. 87), the Liège mines were well organised. This could explain the reluctance of mines located in the Liège coal district to join the collusive structure.
[5] See also *Bulletin d'Information et de Documentation*, vol. II, no. 3, 1946, p. 76.

were still numerous.[6] However, the real number of strategic interests was, fortunately, much smaller than the number of collieries, as a few Belgian financial groups controlled a substantial part of the industry.[7] This made the establishment of a comprehensive coal cartel feasible (Coppé, 1940, p. 201). The overall goal was to regulate the Belgian market and stabilise prices (Kurgan-van Hentenryk and Puissant, 1990, p. 242).

If a firm was caught cheating on its production quotas, the board of the ONC imposed severe penalties (Heaulme, 1948, p. 315). When first set up, the ONC priced industrial coals to match the maximum price of UK coal upon its arrival in Belgium, less import taxes.[8] Cartel members could cede part of their quotas to other members.[9] These quota exchanges were free, except that exchanges between coal basins were restricted to the same type of coal. Quota exchanges between the coal basins for different types of coal required ONC approval. A control system was designed to monitor each member's behaviour. If a member was found cheating, for instance by extracting more than its quota, it was sanctioned in order to preserve the credibility of the cooperative agreement.

The ONC classified sales into three categories. First, collieries' sales to their annex factories and to customers with whom they had strong strategic links were not subject to control. Other sales were

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[6] On the eve of WW1 there were 125 coal mines in Belgium. Mergers reduced this figure to only 70 in 1929. A. Mommen (1994, p. 36) indicates that the number of pits in operation fell by between 30% and 40%. See *Annales des mines*, 13ème série, tome XI, 1937, p. 385.

[7] Two financial groups played a strategic role: the Société Générale de Belgique and the Banque de Bruxelles (G. Kurgan-van Hentenryk and J. Puissant, 1990, p. 242). According to Van der Valk, cited in R.L. Hogg (1986, pp. 94 and 155), in 1927 these two groups controlled almost 42% of total coal production. The massive presence of the Belgian banking sector in the mining industry stemmed from its interest in heavy industry and its determination to control the energy sector (A. Mommen, 1994, p. 36).

[8] See *Bulletin de l'Institut des Sciences Économiques*, 8ème année, no. 2, February 1937, p. 156.

[9] A distinction was made in the cooperative agreements between production, corresponding to minerals extracted, and sales, corresponding to the ore sold or self-consumed by a colliery. See *Annales des Mines*, 13ème série, tome XI, 1937, p. 386.

subject to strict controls through minimum tariffs for each colliery and each type of coal, set upon shipment from the colliery.[10] Cost prices in the Borinage coal district, which faced difficult geological conditions and therefore had the higher production costs, were used as a benchmark (Kurgan-van Hentenryk and Puissant, 1990, p. 243). To show that they were abiding by individual quotas, coal producers had to notify the ONC daily of the tonnage they had shipped (Heaulme, 1948, p. 315). The third category of sales was reserved for the ONC itself: these were sales to large customers such as railroads, public administrations, electricity and gas production plants, and coke factories.[11] Cartel members were not allowed to deal directly with these major customers; that was done by the ONC itself, using special rates and allocating an equitable proportion of these sales to each member.[12]

In the ONC, member firms performed their own sales function and were in direct contact with their customers. This contrasted with the arrangement in the Rhenish-Westphalian Coal Syndicate in Germany, where sales were directly controlled by the cartel and any direct contact between collieries and customers was prohibited (Coppé, 1940, p. 202). Thus, the Belgian organisation was a cartel but not a central selling agency. According to Boulet (1938, p. 125), in December 1937 the ONC was replaced by the Office Belge des Charbons (Obechar). This body was renamed the Comptoir Belge des Charbons (Cobechar) on 26 May 1941, although its aims and operations remained unchanged.[13] Until 1 April 1943, a significant part of

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[10] This tariff system was designed to avoid differences between members' prices in the consumption zones. In addition, the ONC set commissions, discounts and rebates to intermediaries.

[11] *Annales des Mines*, 13ème série, tome XI, 1937, p. 388.

[12] Prices paid to members were, for coal of a given category, the weighted average of all net sale prices per ton in the six-month reference period. Prices were calculated on a "departure from the mine" basis.

[13] B*ulletin d'Information et de Documentation*, vol. II, no. 3, 1946, p. 76. The presence of the Belgian coal cartel after the German invasion of Belgium is also underlined in G. Kurgan-van Hentenryk and J. Puissant (1990, p. 256). This justifies the inclusion of the WW2 period in the analysis.

local and national domestic sales remained unrestricted, provided that producers respected Cobechar's minimum prices (Heaulme 1948, p. 409). After that date, Belgian coal producers had to cede control of their sales activities to a central agency, Cobechar (Heaulme, 1948, p. 409).

The coke market was also cartelised. The Office Belge des Cokes was created in December 1936 to control each firm's tariffs and sales volumes. This collusive structure lasted until March 1939.[14]

Time preference in the Belgian coal industry

In the mining industry, investors tend to have a long time horizon due to their sunk costs. During the nineteenth century and the first half of the twentieth century, this was also true for the Belgian banks that had invested so heavily in the domestic coal industry.

Hogg (1986, p. 82) underlines the importance of banks' investment in Belgian coal. Large Belgian banks invested heavily in the northern basin despite incurring financial losses when it was first exploited. They remained in the coal sector right through the interwar years, even during a span of several years when the northern and southern basins both booked losses.[15] According to Hogg (1986, p. 95) this constant presence was due to institutional factors: "The banking strategy was being formed by conservative men who largely clung to past models of economic development involving the traditional industrial sectors of the nineteenth century."

The evidence, then, shows that the key actors in the Belgian coal industry during this period were taking a long-term approach. This in turn indicates that Belgian coal's collusive structure was characterised by a low time preference and a high discount factor.

Haltiwanger and Harrington (1991, p. 99) find that cartel price

[14] *Bulletin d'Information et de Documentation*, vol. II, no. 3, 1946, p. 68.

[15] The southern basin enjoyed profits during the 1920s except in 1921, 1925 and 1928. During the first half of the thirties, results were negative until 1934 and then positive until 1939. The northern basin showed losses up to 1933. During 1935-39, it recorded profits (F. Baudhuin, 1946, pp. 12-13).

behaviour is strongly pro-cyclical if the discount factor is sufficiently high. In view of the Belgian coal industry's low time preference, the collusive price can be expected to move in line with the business cycle.

3. The model

Economic theory proposes that the degree of competition in a market can vary between two extremes: perfect competition and monopoly. In a perfectly competitive situation, firms price at marginal cost, so that individual profit is zero. If firms are in perfect collusion, they act as a monopoly and the joint profit is maximized. In an imperfectly competitive market, the market price lies somewhere between the marginal cost and the monopoly price. Colluding on the market price enables firms to raise their price and obtain a higher profit than in a perfectly competitive environment. The problem is that, in order to raise the collusion price, each firm must reduce its production. Each adherent to the collusive structure is then tempted to cheat on the cooperative agreement by increasing its own output to get high individual profits. To deter this threat to the cooperative structure, a scheme is designed to penalise firms that break the collusive agreement.

Firms' ability to sustain collusive strategies is a major topic of interest in industrial economics. Following the seminal works of Green and Porter (1984) and Rotemberg and Saloner (1986), Haltiwanger and Harrington (1991) examined the impact of the business cycle on firms' ability to collude on price. They postulated that future demand levels are positively correlated with present demand levels. This hypothesis of a deterministic cycle implies that, in the initial part of the ascending phase of demand, firms are aware that future demand levels will be higher. They therefore have a strong incentive to respect the collusive agreement in order to obtain high profits. If they cheat on the agreement, their future individual profits will be reduced, because other participants will take retaliatory measures to punish them. In this way, the strength of collusive strategies permits firms to sustain a high collusion price when demand for the industry's products increases but remains moderate. According to this model, firms are able to anticipate the turning point in the economic cycle. Consequently, as demand continues its upward trend, they become increasingly aware that the boom is drawing to an end. If the cooperative agreement is to be preserved, the collusive price must be lowered so as to reduce the profitability of deviating from the agreement and thus the incentive to cheat. Once the turning point of the cycle is reached, demand begins to decrease, strengthening the incentive to cheat on the agreement. To keep participating firms loyal, the collusive price must again be reduced. The collusive price cycle appears to anticipate the demand cycle because the collusive price reaches its maximum level before demand starts to fall. In sum, the mechanism causes a reduction in collusive profits before the end of the upswing. The beginning of the economic downswing leads firms to lower the collusive price again in order to deter firms from deviating from the agreement.

Moreover, for a given level of demand, firms' behaviour is not the same in the boom phase as in the bust phase. The opportunity cost associated with retaliation is lowered when firms anticipate decreasing demand, so that firms have an incentive to deviate from the collusive agreement when demand decreases. In addition, deviation profits are higher when demand is high. These two results imply that the collusive structure is unstable when demand is decreasing but even more unstable just before the turning point of the business cycle, when demand is still high.

Knittel and Lepore (2010) examined firms in tacit collusion with a deterministic demand pattern. They found that if the marginal cost of capacity is high (low) enough, prices in booms episodes are lower (higher) than in recessions.

Two assumptions derived from Haltiwanger and Harrington (1991) are econometrically tested:

Assumption 1: When industrial demand pursues its upward trend, the collusion price must be lowered in order to reduce the profitability of deviating from the agreement and thus the incentive to cheat.

Assumption 2: Once the turning point of the business cycle is reached, industrial demand begins to decrease in such a way that the collusion price must be reduced again so as to diminish firms' incentive to cheat.

The model aims at estimating the impact of the economic cycle on Belgian coal firms' ability to sustain collusive strategies in 1901-45. A three-equation model is used that comprises a coal demand equation, an imported coal supply equation and a coal supply equation.

In the Belgian market, domestic producers were presumed to have a competitive advantage over foreign producers, thanks to lower transportation costs.[16] The coexistence of domestic collieries with imported products can be formalised by considering that Belgian producers were Stackelberg leaders while foreign producers acted as a competitive fringe. Therefore, the demand for Belgian coal was a residual demand corresponding to the differential between total coal demand and imports.

Q^d, the residual coal demand for Belgian producers, is defined as:

$$Q^d = Q^m - Q^i \qquad (1)$$

where Q^m denotes total coal demand and Q^i coal imports.

A coal demand function of the following form is estimated:

$$Q^m = D\,(P, X^*, \alpha^*) + w \qquad (2)$$

where D (.) is the coal demand function on the Belgian market, P the market price, X^* a group of exogenous variables, α^* the coefficients associated with the demand function, and w an error term.

In a competitive market, market price corresponds to marginal production cost. When firms have some market power, their price

[16] Data on coal prices for the UK and Belgium for 1929-37, published in C. Demeure (1939, p. 156), indicate that Belgian prices were significantly lower than those of the UK.

is higher than their marginal cost. In perfect market collusion, firms set their prices by equalizing marginal revenue and marginal cost.

The supply function defined is of the following form:

$$P = c\,(W^{*}, Q^{d}, \mu^{*}) - \lambda h\,(Q^{d}, X^{*}, \lambda^{*}) + z \qquad (3)$$

where $P + \lambda h$ (.) corresponds to the firm's marginal revenue, X^{*} to the exogenous variables, c (.) to the marginal cost, W^{*} to the exogenous variables, Q^{d} to the residual coal demand for Belgian producers, λ^{*} and μ^{*} to the coefficients associated with the supply function and z to the residual variable of the supply function. The λ parameter measures the degree of market power and ranges between 0 (competitive market) and 1 (collusive market). Intermediate values correspond to an imperfectly competitive market.

Following Bresnahan (1982), the degree of market power λ can be identified when the marginal cost depends on production levels. This feature permits us to incorporate the hypothesis of decreasing returns usually observed in mining industries. In this case, the identification of the λ parameter makes it necessary to introduce an interaction term into the demand function, so that a variation in one of the exogenous variables of the demand equation induces a double shift of the demand function, in other words both a translation and a rotation movement. Further, Perloff and Shen (2012) show that collinearity problems arise when both the marginal cost and demand equations are linear. The specific variable that must interact with the coal demand function could correspond to a substitute for coal ore. Steen and Salvanes (1999, p. 159) underline that it is useful to introduce not one but two interaction terms in order to produce more accurate estimates. A similar approach also appears in Jaffry et al. (2003). Accordingly, two interaction terms are considered here.

The coal demand equation

In order to specify the demand for coal, the real price of coal (P_t^r) and the real GDP of Belgium ($RGDPBEL_t$) are introduced as a proxy for the performance of the Belgian economy. The higher Belgian real

GDP, the higher the coal demand directed to Belgian collieries. The Netherlands' real GDP ($RGDPNED_t$) is added, because the Dutch coal industry was a great coal supplier for Belgium.[17] A linear time trend and two binary variables $WW1_t$ and $D21_t$ are also included. Moreover, two interaction terms are added in order to comply with the identification condition of the λ parameter. These are P_t^r*$MINERS_t$ and P_t^r*$OIL\_PRICE\_BEF_t$.[18] In accordance with the methodology used by Bresnahan (1982), given the decision to introduce these two interaction terms, it was also necessary to introduce both the total number of workers in Belgian collieries ($MINERS_t$) and the crude oil price in Belgian francs ($OIL\_PRICE\_BEF_t$) as explanatory variables. Hence the following demand function:

$$Q_t^m = \alpha_0 + \alpha_1 + P_t^r + \alpha_2 P_t^r{*}MINERS_t + \alpha_3 P_t^r{*}OIL\_PRICE\_BEF_t + \\ + \alpha_4 RGDPBEL_t + \alpha^5 TIME_t + \alpha_6 RGDPNED_t + \alpha_7 MINERS_t + \\ + \alpha^8 OIL\_PRICE\_BEF_t + \alpha_9 WW1_t + \alpha_{10} D21_t + u_t \quad (4)$$

Estimates should lead to $\partial Q_t^m / \partial P_t^r = \alpha_1 + \alpha_2 MINERS_t + \alpha_3 OIL\_PRICE\_BEF_t < 0$ by application of the law of demand. In addition, one expects $\partial Q_t^m / MINERS_t = \alpha_2 P_t^r + \alpha_7 < 0$ because the labour factor (i.e. $MINERS_t$) and the circulating capital factor (i.e. coal ore) can be considered, up to a point, as substitutes. More precisely, under the hypothesis of substitution of production factors, an increase in the demand for labour in the economy (i.e. higher level of $MINERS_t$) should be compatible with a reduction in the demand for circulating capital (i.e. lower level of Q_t^m). This should induce a negative demand shock for coal, so that, graphically, the demand for coal should shift to the left.

However, this substitution process is limited by technical constraints because coal energy remained indispensable in the first half

[17] Estimates obtained with inclusion of the real GDP of Germany proved to be unsatisfactory. Hence the absence of this variable.

[18] In order to comply with the identification constraints specified by T.F. Bresnahan (1982), variables interacted with the real coal price must have an impact on the coal demand. The labour factor is taken into account here through the $MINERS_t$ variable and the real price of petroleum through the $OIL\_PRICE\_BEF_t$ variable. C. Jung and B.J. Seldon (1995, pp. 44-45) followed this line of reasoning.

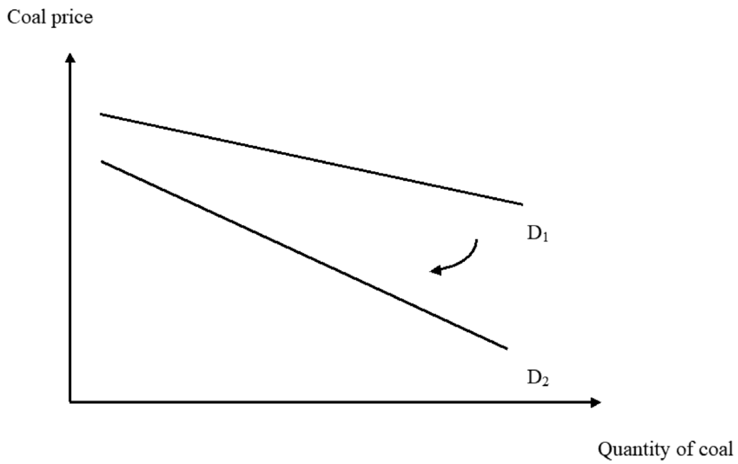
of the twentieth century. Thus the demand for coal becomes step-by-step less price elastic when the quantity of labour is higher. This implies that the absolute value of $\partial Q_t^m / \partial P_t^r$ is lowered when $MINERS_t$ increases.

The following results are obtained:

$$\left.\begin{array}{r} \partial Q_t^m / \partial P_t^r < 0 \\ \partial Q_t^m / \partial MINERS_t < 0 \end{array}\right\} \Rightarrow \partial \left(Q_t^m\right)^2 / \partial P_t^r \, \partial MINERS_t = \alpha_2 > 0$$

As shown in Figure 2, given the postulated negative value of $\partial Q_t^m / \partial P_t^r$ and the positive value associated with the second derivative $\partial (Q_t^m)^2 / \partial MINERS_t$ an increase in the quantity of the labour factor (i.e. increase of $MINERS_t$) should rotate demand from D_1 to D_2.[19]

FIGURE 2
The rotation of demand from D_1 to D_2 as the economy becomes more labour-intensive



Given that coal and oil are substitutes, we have $\partial Q_t^m / \partial OIL\_PRICE\_BEF_t = \alpha_3 P_t^r + \alpha_8 > 0$. Any increase in the real price of oil should positively affect the demand for coal. We have:

[19] A reduction in the number of miners should reverse the mechanism: the demand should rotate from D_2 to D_1.

$$\left.\begin{array}{r}\partial Q_t^m / \partial P_t^r < 0 \\ \partial Q_t^m / \partial OIL\_PRICE\_BEF_t < 0\end{array}\right\} \Rightarrow \partial \left(Q_t^m\right)^2 / \partial P_t^r \, \partial OIL\_PRICE\_BEF_t = \alpha_3 < 0$$

In addition, the real GDP of the Netherlands is introduced. Available productivity data show that the Dutch coal industry was more efficient than its Belgian counterpart (see Table 7 in Appendix A.1). If the Dutch economy were to experience an economic recovery, its coal extraction should be expected to rise and its coal exports to Belgium should increase as well, thanks to higher productivity.[20] A similar logic could be applied to Germany, the UK and Poland (but not to France, whose productivity was significantly lower – see Table 7). However the inclusion of these countries in the demand equation leads to insignificant coefficients.[21]

The imported coal supply equation

The importance of coal imports relative to total coal sales in Belgium highlights the strength of the foreign pressure on the Belgian coal market.[22] It is therefore necessary to take account of business cycle conditions in the main coal exporters to Belgium through their real GDP. This concerns Germany ($RGDPGER_t$) and the Netherlands ($RGDPNED_t$). In addition, the state of the French economy is considered through the differential of real GDP between Belgium and France with a one-year lag ($DIFFBELFR_{t-1}$) A positive difference indicates that economic growth is higher in Belgium than in France. In this case, French coal producers might be tempted to increase their sales to Belgium. It must be stressed that all these variables have not

[20] France and Belgium were the natural markets for a significant part of Dutch coal (L.A. Smeets 1937, p. 1097).
[21] Germany is considered in the import supply equation.
[22] Specifically, Belgium's coal imports increased steadily relative to domestic demand, from 13% in 1901 to 30% in 1913, but fell abruptly to zero during WW1. After the war, the ratio rose rapidly to average 29% from 1923 to 1931. From 1931, it fell steadily (except in 1937, owing to import quotas) and ended at almost zero again during WW2. See Figure 1 for an annual profile of coal imports.

been considered in the same specification because two specifications were estimated. In addition, account was taken of several historical events through dummies. Starting in October 1931, import quotas were imposed on coal products to reduce competitive pressure on the Belgian coal market (Leener, 1934, p. 48-49). The protection system was completed with a tax on coal imports at the start of January 1933. At the beginning of 1936, coal imports were limited to 33.8% of import volumes for the first quarter of 1931.[23] It is postulated that the restrictions on coal imports lasted until 1939.[24] These historical elements are incorporated in the model through the binary variable $QUOTAS_t$. Further, the consequences of the Second World War on coal imports were taken into account through the $WW2_t$ binary variable. The $D14_t$ binary variable takes into account the sudden decrease in coal imports at the start of WW1. The $D21_t$ variable represents the year 1921: in that year, the Belgian economy slumped and coal imports were likely to have been affected.[25] During the first half of the twentieth century, Belgium's coal imports peaked in 1929. This is incorporated by means of binary variable $D29_t$. The $D38_t$ binary variable represents the strengthening of protective barriers against coal imports in October 1938 (Hogg, 1986, p. 93). Accordingly, the two following specifications have been estimated:

$$
\begin{aligned}
Q_t^i = \beta_0 + \beta_1 P_t^r + \beta_2 DIFFBELFR_{t-1} + \begin{cases} \beta_{31} RGDPNED_t \\ \beta_{32} RGDPGER_t \end{cases} + \\
+\beta_4 QUOTAS_t + \beta_5 WW2_t + \beta_6 D14_t + \beta_7 D21_t + \\
+\beta_8 D29_t + \beta_9 D38_t + \beta_{10} Q_{t-1}^i + v_t
\end{aligned}
\qquad (5)
$$

[23] Cf. *Annales des Mines*, 13ème série, tome XI, 4ème livraison, 1937, p. 384.

[24] Historical documents indicate that the coal import quota system was interrupted in 1937. This could explain the sudden and transitory increase in coal imports that year 1937 (see Figure 1 in the article). Nevertheless, an import tax was still in applied, so coal imports remained limited (*Annales des Mines*, 13ème série, tome XI, 4ème livraison, 1937, pp. 384-385). Available annual statistics on Belgian coal imports show that they were near zero from 1940 to 1945.

[25] This change appears clearly in Figure 1 with the abrupt end of the rising phase of coal imports.

It is important to note that $RGDPNED_t$ and $RGDPGER_t$ after the bracket do not appear in the same specification but in two distinct ones. The same goes for all the specifications presented below.

The coal supply equation

The supply function is specified as follows:

$$P_t = -\left(\frac{\lambda}{\alpha_1 - \beta_1 + \alpha_2 MINERS_t + \alpha_3 OIL\_PRICE\_BEF_t}\right) Q_t^d + c\left(W_t^*, Q_t^d, \mu^*\right) + z_t \qquad (6)$$

with α_1 the slope of the market demand, β_1 the slope of the import supply and z an error term.

Component c (W^*, Q^d, μ^*), which corresponds to the marginal production cost, has to be estimated in the absence of any direct observation of the marginal cost. Various explanatory variables corresponding to the W^* vector have been selected. The unit cost of each production factor was considered. First, the labour factor through the real gross wage at vein ($RGWV_t$). Next, the unit cost of capital through the interest rate (I_RATE_t). Finally, the residual coal demand for Belgian producers' (Q_SALES_t) was included so as to incorporate the potential impact of decreasing returns, characteristic of the mining industry. Notice that Q_SALES_t corresponds to Q^d.

$$c(W^*, Q^d, \mu^*) = \mu_0 + \mu_1\, RGWV_t + \mu_2\, I\_RATE_t + \mu_3\, Q\_SALES_t \qquad (7)$$

According to Haltiwanger and Harrington (1991), for a given demand level, the collusive price should be higher during booms than during recessions.[26]

It is assumed that the λ parameter, i.e. the degree of market power, depends on changes in coal stocks on the one hand and excess production capacity, or the $D3541_t$ dummy, on the other.

[26] The theoretical results presented in the introduction underline the impact of the demand cycle on firms' ability to collude and, by extension, on the degree of market power within an industry. So the degree of market power depends on the demand cycle.

$$\lambda_t = \lambda_0 + \lambda_1 STOCK_t + \begin{cases} \lambda_{21} CAPA2_t \\ \lambda_{22} D3541_t \end{cases} \tag{8}$$

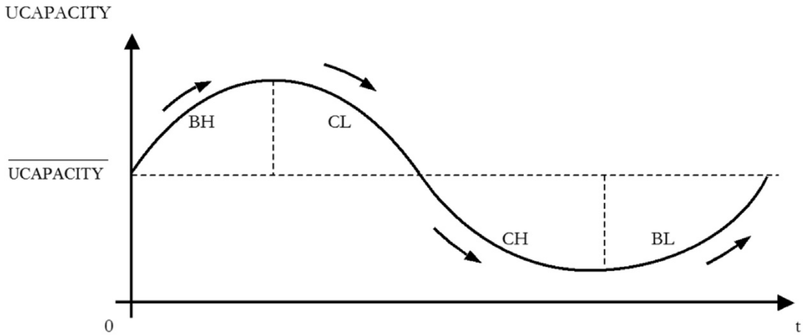
Historically, for the Belgian collieries it is possible to identify several episodes of economic crisis. The use of the Q_t^d series, viz. the residual demand for Belgian coal, leads us to distinguish between boom phases and crisis phases. A boom phase (conversely, a crisis phase) corresponds to an increasing trend of the series (conversely, a decreasing trend of the series). Before the Great War, 1904 is signalled as a crisis year. A second crisis corresponds to the war years. During the 1920s, three years appear as crisis episodes (1921, 1925 and 1928). During the 1930s, the crisis of the early part of the decade is detected from 1930 to 1933, while another crisis is reported in 1938. The last crisis phase corresponds to the period of the Second World War.

To test this result, a vector of binary variables Mt was considered, equal to one if the state considered exists and zero if not. The vector Mt permits us to model the Belgian economic cycle. A set of binary variables is introduced to depict the range of possible conjunctural states of the market. In order to avoid λ being zero when Mt is zero, Rosenbaum and Sukharomana's $(1 + \eta M_t)$ term (2001) is used. Two methods are used to define this dummy variable. The first entails constructing a binary variable equal to 0 (1) when demand follows an upward (downward) trend.[27] Rosenbaum and Sukharomana (2001) used a similar approach. This method allows us to distinguish between upward and downward movements in demand, but not between phases of high and low demand. Because of this shortcoming, we considered another way of proceeding.

The second approach consists in merging the direction of the demand slope (positive or negative) and the level of demand (high or low). Four possible states of the economic conjuncture can be defined. These different situations can be depicted more precisely schematically:[28]

[27] Details of the construction of this variable are given in Appendix A.10.
[28] In order to distinguish between high and low demand, the mean level of capacity use for Belgian coalfields in 1901-1945 ($\overline{\text{UCAPACITY}}$) serves as a benchmark.

FIGURE 3
The four phases of the business cycle



From the previous figure, four binary variables are defined:

TABLE 2
The four conjunctural phases

		Level of demand	
		Low	High
Evolution of demand	Increasing	DBL (phase of weak expansion)	DBH (phase of strong expansion)
	Decreasing	DCH (phase of deep crisis)	DCL (phase of shallow crisis)

The M_t binary variable is used to model the economic cycle, which is formalized with $DQTOTALEES_t$ on the one hand, or with three binary variables defined in Table 2, on the other.[29] Therefore, two approaches are considered, summarised in equation (9):

$$1+\eta M_t = 1+\begin{cases} \eta_{01} DQTOTALEES_t \\ \eta_{02} DBH1_t + \eta_{12} DCL1_t + \eta_{22} DCH1_t \end{cases} \qquad (9)$$

[29] $DQTOTALEES_t$ is a binary variable equal to 0 (1) if the trend corresponding to the exponential smoothing of the $TOTALQ_t$ chronicle is increasing (decreasing). Details are given in appendix A.10.

By combining expressions (8) and (9), the market power expression becomes:

$$\lambda_t = \left(\lambda_0 + \lambda_1 STOCK_t + \begin{cases} \lambda_{21} CAPA2_t \\ \lambda_{22} D3541_t \end{cases} \right) * $$
$$ * \left(1 + \begin{cases} \eta_{01} DQTOTALEES_t \\ \eta_{02} DBH1_t + \eta_{12} DCL1_t + \eta_{22} DCH1_t \end{cases} \right) \qquad (10)$$

By combining equations (6) and (10), the domestic coal supply function becomes:

$$P_t = \left(\lambda_0 + \sum_{i=1}^{n} \lambda_i Z_t^i \right) * \left(1 + \eta M_t\right) *$$
$$ * \left(\frac{1}{\alpha_1 - \beta_1 + \alpha_2 MINERS_t + \alpha_3 OIL\_PRICE\_BEF_t} \right) \qquad (11)$$
$$Q_t^d + \pi P_{t-1}^r + z_t$$

Finally, we consider the three-equation model discussed below.

The three-equation model

Several model specifications were estimated. They depend on the specification of the following four components: the supply of coal imports, the marginal cost, the λ_t parameter, which corresponds to market power, and the economic cycle component. We consider the three-equation model given below:

$$Q_t^m = \alpha_0 + \alpha_1 P_t^r + \alpha_2 P_t^r * MINERS_t + \alpha_3 P_t^r * OIL\_PRICE\_BEF_t +$$
$$+ \alpha_4 RGDPBEL_t + \alpha_5 TIME_t + \alpha_6 RGDPNED_t + \alpha_7 MINERS_t + \qquad (12)$$
$$+ \alpha_8 OIL\_PRICE\_BEF_t + \alpha_9 WW1_t + \alpha_{10} D21_t + u_t$$

$$Q_t^i = \beta_0 + \beta_1 P_t^r + \beta_2 DIFFBELFR_{t-1} + \begin{cases} \beta_{31} RGDPNED_t \\ \beta_{32} RGDPGER_t \end{cases} +$$
$$+ \beta_4 QUOTAS_t + \beta_5 WW2_t + \beta_6 D14_t + \beta_7 D21_t + \beta_8 D29_t + \qquad (13)$$
$$+ \beta 38_t + \beta_{10} Q_{t-1}^i + v_t$$

$$
\begin{aligned}
P_t^r = {} & \mu_0 + \mu_1 RGWV_t + \mu_2 I\_RATE_t + \mu_3 Q\_SALES_t - \\
& -\left(\lambda_0 + \lambda_1 STOCK_t + \left\{ \begin{array}{l} \lambda_{21} CAPA2_t \\ \lambda_{22} D3541_t \end{array} \right. \right) * \\
& * \left(1 + \left\{ \begin{array}{l} \eta_{01} DQTOTALEES_t \\ \eta_{02} DBH1_t + \eta_{12} DCL1_t + \eta_{22} DCH1_t \end{array} \right. \right) * \\
& * \left(\frac{1}{\alpha_1 - \beta_1 + \alpha_2 MINERS_t + \alpha_3 OIL\_PRICE\_BEF_t} \right) * \qquad (14) \\
& * Q\_SALES_t + \pi P_{t-1}^r + z_t
\end{aligned}
$$

To ensure identification of the degree of oligopoly, a necessary condition is that the demand function not be separable in both the interaction variables introduced (Lau, 1982).

4. Econometric results

The stationarity at level of each variable was checked through various unit root tests.[30] The approach chosen has two stages. Estimates were made based on annual data for 1901-45. First, each equation was estimated individually by 2SLS in order to define a form compatible with econometric requirements. In order to check for the absence of serial correlation, three tests were carried out: a Ljung-Box test, a Breusch-Godfrey test[31] and a cumulated periodogram test.[32] In a second step, the whole three-equation system was estimated by NL3SLS. Use was made of the methodology defined by Fair (1970), adding the endogenous lagged variable as an exogenous variable in equations (13) and (14) so as to remedy serial correlation of residuals.

---

[30] These tests are presented in Appendix A.13.
[31] Instead of using the χ^2 statistics, a Fisher test was performed, because the χ^2 form of the Breusch-Godfrey test tends to lead to a rejection of the null hypothesis of absence of serial correlation of residuals (A. C. Darnell, 1994, p. 25).
[32] The Durbin-Watson test was not applied because of its shortcomings (W.H. Greene, 2018, p. 1003).

The individual tests for separability in $MINERS_t$ and $OIL\_PRICE\_BEF_t$ given in Table 3 below establish that the null hypotheses of separability are rejected at a 0.5% significance level in both cases and for both specifications. The joint hypothesis of separability in both $MINERS_t$ and $OIL\_PRICE\_BEF_t$ is also rejected. Thus, the demand function is not separable in $MINERS_t$ and $OIL\_PRICE\_BEF_t$ and so it is possible to use both interaction terms, $P_t^{r*}MINERS_t$ and $P_t^{r*}OIL\_PRICE\_BEF_t$ to identify λ.

TABLE 3
Separability tests

	Specification A		Specification B	
	χ^2-statistic	Prob.	χ^2-statistic	Prob.
Individual separability tests				
H_0: $\alpha_2 = 0$	12.921	0.0003	28.143	0.0000
H_0: $\alpha_3 = 0$	8.450	0.0036	28.132	0.0000
Joint separability test				
H_0: $\alpha_2 = \alpha_3 = 0$	18.379	0.0001	28.146	0.0000

In Table 4, the statistical tests indicate the absence of any residual autocorrelation. A Sargan-Hansen test was implemented to test for exogeneity of instruments and a test derived from Hausman (1978) was applied to test for exogeneity of explanatory variables.

4.1 The coal demand equation

The estimated coefficients for various demand equation specifications do not contradict the theoretical results. The estimated coefficients appear highly significant. Coal demand is negatively correlated with the real price of coal. Both Belgian and Dutch real GDP have a positive effect on coal demand. The positive and high coefficients associated with economic activity in the Netherlands reveal the strong interdependence between the two economies.[33] The

[33] The estimates associated with Belgian real GDP are logically higher than those associated with Dutch real GDP. In fact, Belgian coal demand depended mainly on domestic factors.

TABLE 4
Estimated results of the three-equation system*

	Specification A				Specification B			
	Coef.	Std. err.	Z	P > |Z|	Coef.	Std. err.	Z	P > |Z|
Coal demand equation								
Constant	3.255E+7	1.165E+7	2.79	0.0052	4.666E+7	1.032E7	4.52	0.0000
P^r_t	-3.312E+7	8.649E+6	-3.83	0.0001	-4.387E+7	7.399E+6	-5.93	0.0000
$RGDPBEL_t$	1.806E+5	3.167E+4	5.70	0.0000	2.011E+5	3.068E+4	6.56	0.0000
$RGDPNED_t$	1.452E+5	1.658E+4	8.76	0.0000	1.520E+5	1.654E+4	9.19	0.0000
$MINERS_t$	-311.835	73.884	-4.22	0.0000	-416.881	73.958	-5.64	0.0000
$OIL\_PRICE\_BEF_t$	9.630E+4	2.440E+4	3.95	0.0001	1.066E+5	1.557E+4	6.84	0.0000
$TIME_t$	-4.759E+5	6.040E+4	-7.88	0.0000	-5.459E+5	6.473E+4	-8.43	0.0000
$P^r_t * MINERS_t$	248.109	56.040	4.43	0.0000	319.222	52.852	6.04	0.0000
$P^r_t * OIL\_PRICE\_BEF_t$	-6.460E+4	2.014	-3.21	0.0013	-7.073E+4	1.206E+4	-5.86	0.0000
$WW1_t$	-2.917E+6	5.999E+5	-4.86	0.0000	-3.171E+6	6.083E+5	-5.21	0.0000
$D21_t$	-4.504E+6	1.185E+6	-3.80	0.0001	-4.171E+6	1.164E+6	-3.58	0.0003
R^2	0.960				0.960			
Ljung-Box (2 lags)	0.443				0.464			
Ljung-Box (10 lags)	0.289				0.317			
Ljung-Box (20 lags)	0.166				0.171			
BG test (1 lag)	0.279				0.296			
BG test (4 lags)	0.872				0.687			
Cum. period. test	0.1417				0.1391			

TABLE 4 *(continued)*

	Specification A				Specification B			
	Coef.	Std. err.	Z	P > |Z|	Coef.	Std. err.	Z	P > |Z|
Imported coal supply equation								
Constant	-6.479E+6	1.255E+6	-5.16	0.0000	-3.406E+6	1.245E+6	-2.73	0.0062
P^r_t	3.602E+6	7.448E+5	4.84	0.0000	1.280E+6	7.271E+5	1.76	0.0783
$DIFFBELFR_{t-1}$	4.564	1.428E+4	3.19	0.0014	5.835E+4	1.455E+4	4.01	0.0000
$RGDPGER_t$	2.727E+4	6.640	4.11	0.0000	-	-	-	-
$RGDPNED_t$	-	-	-	-	2.545E+4	6.859E3+3	3.71	0.0002
$QUOTAS_t$	-7.608E+5	3.032E+5	-2.51	0.0121	-1.029E+6	3.039E+5	-3.39	0.0007
$WW2_t$	-3.472E+6	6.113E+5	-5.68	0.0000	-3.659E+6	6.424E5	-5.69	0.0000
$D14_t$	-8.554E+6	5.963E+5	-14.34	0.0000	-8.872E+6	6.282E+5	-14.12	0.0000
$D21_t$	2.352E+6	6.481E+5	3.63	0.0002	2.903E+6	6.548E+5	4.43	0.0000
$D29_t$	1.993E+6	6.487E+5	3.07	0.0021	1.554E+6	6.365E+5	2.44	0.0146
$D38_t$	-2.055E+6	6.787E+5	-3.03	0.0025	-1.999E+6	6.813E+5	-2.93	0.0033
Q^i_{t-1}	0.844	3.719E-2	22.68	0.0000	0.912	3.784E-2	24.10	0.0000
R^2	0.965				0.965			
Ljung-Box (2 lags)	0.885				0.913			
Ljung-Box (10 lags)	0.111				0.141			
Ljung-Box (20 lags)	0.016				0.019			
BG test (1 lag)	0.861				0.830			
BG test (4 lags)	0.563				0.759			
Cum. period. test	0.1382				0.1218			

TABLE 4 *(continued)*

	Specification A				Specification B			
	Coef.	Std. err.	Z	P > |Z|	Coef.	Std. err.	Z	P > |Z|
Domestic coal supply equation								
Marginal cost								
Constant	0.582	0.200	2.91	0.0036	0.238	0.187	1.27	0.2023
$RGWV_t$	0.845	0.374	2.26	0.0238	1.150	0.361	3.19	0.0014
I_RATE_t	4.510E-2	1.649E-2	2.73	0.0062	1.590E-2	1.514E-2	1.05	0.2936
Q_SALES_t	-1.474E-8	7.489E-9	-1.97	0.0491	-9.616E-9	5.569E-9	-1.72	0.0844
Market power								
Constant	5.167E-3	1.049	0.49	0.6222	-0.116	3.950E-2	-2.94	0.0032
$STOCK_t$	-1.159E-8	1.058E-8	-1.39	0.1635	-6.109E-8	1.949E-8	-3.13	0.0017
$CAPA2_t$					7.509E-8	1.949E-8	3.85	0.0001
$D3541_t$	8.283E-2	4.151E-2	1.99	0.0460	-	-	-	-
P^r_{t-1}	0.292	0.119	2.46	0.0139	0.493	0.115	4.28	0.0000
Economic cycle								
$DQTOTALEES_t$	-0.795	0.340	-2.34	0.0193	-	-	-	-
$DBH1_t$	-	-	-	-	-0.998	4.154E-3	-240.36	0.0000
$DCL1_t$	-	-	-	-	-1.002	5.004E-3	-200.21	0.0000
$DCH1_t$	-	-	-	-	-1.011	1.716E-2	-58.94	0.0000
R^2	0.685				0.794			
Ljung-Box (2 lags)	0.991				0.428			
Ljung-Box (10 lags)	0.268				0.084			

TABLE 4 *(continued)*

	Specification A				Specification B			
	Coef.	Std. err.	Z	P > |Z|	Coef.	Std. err.	Z	P > |Z|
Ljung-Box (20 lags)	0.024				0.014			
BG test (1 lag)	0.645				0.549			
BG test (4 lags)	0.523				0.998			
Cum. period. test	0.0704				0.1721			
Sargan-Hansen test	0.051				0.045			
Hausman test	0.270				0.680			

* The Ljung-Box test indicates the probability associated with the Q-statistics. BG corresponds to the Breusch-Godfrey test for one and four lags (probability associated with the Fisher statistic is indicated). Durbin's cumulated periodogram test is a serial error correlation test based on spectral analysis techniques. It presents the maximum difference between the theoretical distribution function of a white noise process and the estimate's residuals. An empirical value lower than the critical value indicates that the difference does not differ significantly from zero and the null hypothesis of serial correlation is rejected. These critical values are 0.2881 (1%), 0.2404 (5%) and 0.2157 (10%).

coefficient associated with the number of workers in Belgian collieries is negative.[34] The oil price has a positive effect on coal demand because oil is a substitute. The linear temporal trend has a negative effect due to the economic crisis of the 1930s. Both interaction terms are highly significant. The estimates do not contradict expected signs (i.e. $\alpha_1 < 0$, $\alpha_2 > 0$, $\alpha_3 < 0$, $\alpha_7 < 0$ and $\alpha_8 > 0$). The negative effect of WW1t on coal demand is clearly established by these results. The negative coefficient associated with $D21_t$ indicates that the decline in economic activity in 1921 depressed the demand for coal. The absence of serial correlation of residuals was checked by means of various statistical tests.

In addition, we computed the derivative $\partial Q_t^m / \partial P_t^r$ for each of the estimated specifications. This element corresponds to $\alpha_1 + \alpha_2$ $MINERS_t + \alpha_3$ $OIL\_PRICE\_BEF_t$. The standard errors of estimated coefficients were obtained by applying the delta method. Next, we computed the price elasticity of demand. As expected, the estimates were significant and negative. A statistical test was run to compare the price elasticities of demand. The z-statistic is equal to -0.36, allowing us to conclude that both elasticities do not differ significantly.[35] The result obtained in specification (A) indicates that a real increase of 1 Belgian Franc in the unit price of coal is associated with a reduction in coal demand of about 4.6 million tons per year. In terms of the price elasticity of demand, the results obtained for specification (A) suggest that a 1% increase in the unit price of a ton of coal is associated with a reduction of 0.34% in the quantity of demand for coal ore per year.

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[34] *A priori*, there should be a positive link between the coal demand function (i.e. Q_t^m) and the number of workers in the Belgian collieries (i.e. $MINERS_t$), because a larger number of miners should correspond to a higher demand for coal. However, according to data reported by A. Coppé (1940, p. 153), from 1921-1937 the total number of workers in the Belgian coal districts fell by almost 12%. This could be explained by mechanisation in the collieries, which according to F. Baudhuin (1946, p. 13ff) made rapid headway during the interwar period.

[35] Following C.C. Clogg et al. (1995, p. 1276) $z = \frac{[-0.341073 - (-0,280792)]}{\sqrt{0.127473^2 + 0.1067119^2}} = -0.36$ where values in the denominator correspond to the standard errors of the elasticities obtained by applying the delta method.

TABLE 5
Values of the derivative and of the price elasticity of demand

	Specification A				Specification B			
	Coef.	Std. err.	Z	P > |Z|	Coef.	Std. err.	Z	P > |Z|
$\partial Q^m_t/\partial P^r_t$	-4.637E+6***	1.733E+6	-2.68	0.0075	-3.817E+6***	1.451E+6	-2.63	0.0085
$\varepsilon_{Q/P}$	-0.34				-0.28			

Note: $\partial Q^m_t/\partial P^r_t = \alpha_1 + \alpha^2$ MINERS$_t$ + α_3 OIL_PRICE_BEF$_t$. Standard errors have been computed by implementation of the delta method. Significance at 1% is indicated by ***. The price elasticity of demand is $(\partial Q_t/\partial P_t)$*(P/Q) where P and Q correspond respectively to the average level of the unit price computed over the 1901-1945 period (equal to 1.3498 real Belgian franc) and to the average level of coal demand over the 1901-1945 period (equal to 18,351,053.61 tons per year).

4.2 The imported coal supply equation

The estimates for the imported coal supply are mostly highly significant and with the expected sign. The real price of coal has a positive effect on imported coal supply. German real GDP ($RGDPGER_t$) has a highly significant positive effect on imported coal supplies in Belgium because a recovery in the German economy tends to induce higher domestic coal production, so that German collieries are forced to increase their exports to Belgium or France in order to avoid a rapid increase in volumes of stored coal.[36] Coal ore is difficult to stockpile for long periods of time because its calorific properties are altered by long storage. This positive relationship between greater economic dynamism on the one hand and higher coal exports to Belgium on the other was also associated with the German collieries' dumping strategy. For similar reasons, Dutch real GDP ($RGDPNED_t$) also has a significant and positive impact on coal

[36] The comparison of an annual index of German coal production (1901=100) based on a series gleaned from B. Etemad et al. (1991, p. 45) and the $RGDPGER_t$ index (1901: 100) indicates that the index of coal production is higher than the index of real GDP for nearly 89% of the period analysed (40 years out of 45). This suggests that coal mining was more dynamic than the German economy overall over most of the period 1901-1945. In addition, these two indices are highly correlated (0.873 in 1901-1945 and even 0.939 in 1901-1944). Thus, an increase in real German GDP was accompanied by a rise in German coal production. Relative to the base year, the increase in coal production was greater than that in German economic activity, giving German collieries an incentive to increase their exports so as to avoid storing part of their additional production.

imports in Belgium. The significant and positive coefficient associated with $DIFFBELFR_{t-1}$ i.e. the difference between the real GDP of Belgium and France with a one-year lag, suggests that when the Belgian economy is more dynamic than the French economy, coal imports in Belgium tend to increase with a one-year lag. The Second World War had a significant and negative impact on coal imports in Belgium, in accordance with Figure 1 in Section 2 above. Estimates reveal the effectiveness of the coal import quotas strategy ($QUOTAS_t$), while the beginning of WW1 induced a drastic drop in Belgian coal imports ($D14_t$ dummy). The positive and significant coefficient associated with the $D21_t$ dummy seems counterintuitive at first. The explanation is that although the Belgian economy declined in 1921, economic conditions were even worse in France, the UK and Germany.[37] The main coal exporters (Germany, Netherlands and the UK) tried to compensate for the reduction in their exports to France and the drop in their domestic sales (Germany and the UK) by increasing exports to Belgium.[38] The $D29_t$ dummy systematically has a positive and significant coefficient that is consistent with the fact that both Belgian demand for coal and coal imports peaked that year. The efficacy of the decision taken in October 1938 to strengthen protective barriers against coal imports is not contradicted by the negative and significant coefficient of the $D38_t$ binary variable. Statistical tests show the absence of serial correlation of residuals.

[37] Available data on real GDP (1913 = 100) indicate that the GDP index in 1921 was 94.1 in Belgium but even lower in several other countries: 87.5 in Germany, 87.1 in the UK and 83.5 in France (while the Dutch index stood at 122.9). The point to be underscored is that in 1921 most of the leading coal exporters to Belgium faced harsher economic conditions than the Belgian economy. See Appendix A.7 for data sources on real GDP and R. Leboutte et al. (1998, p. 144) for data on Belgian industrial production.

[38] From December 1920 to June 1921 total exports of coal to France fell by nearly 80%. Specifically, French imports from Germany and the UK, the top two coal exporters to France, fell drastically during the first half of 1921. These data are obtained taken from Revue de l'Industrie Minérale. In the same period, coal exports to Belgium increased, rising from 1,541,097 tons in 1920 (*Annales des Mines de Belgique*, 1921, p. 1312) to 5,628,574 tons in 1921 (*Annales des Mines de Belgique*, 1922, p. 1060).

4.3 The domestic supply equation

We consider successively the three components of the domestic supply function.

The marginal cost component

Owing to the impossibility of directly measuring marginal production costs, an econometric estimation was performed. Labour costs were taken into account through an index of real wages ($RGWV_t$). All the estimates are significant with a positive sign as expected. We also introduced a proxy for the unit cost of capital (I_RATE_t). The estimated coefficient is significant and positive as expected. The decreasing returns phenomenon that is usually found in extractive industries was considered with the volume of coal sales within Belgian territory i.e. Q_SALES_t. At first glance, a positive effect should be expected because higher volumes of sales of coal ore should imply higher extraction levels, which should imply an increase in the average depth of extraction. However, the estimates do not support this interpretation because their sign is negative. The negative sign does not imply the absence of decreasing returns but it could stem from learning and mechanisation effects stronger than the decreasing returns phenomena specific to extractive industries.[39]

The market power component

The second component of the domestic supply function corresponds to the determinants of market power. The possible impact of coal stocks on market power was assessed through the $STOCK_t$ index. The estimated coefficients are negative and significant at 0.5% in one case out of two. Next, we considered the impact of excess production capacity $CAPA2_t$ in specification (B). According to Davidson and Deneckere (1990), collusive firms maintain excess production

[39] The estimated coefficients are low, suggesting that this variable has a weak impact on the marginal cost.

capacity to preserve the credibility of the punishment mechanism. More precisely, if a collusive firm tries to deviate from the collusive agreement, excess capacity permits other collusive firms to increase their production in order to punish the cheater. Excess capacity is used to warn participants against deviating from the collusive agreement. However, excess capacity can also be explained by coal demand being lower than coal output, in which case excess capacity reduces firms' market power by increasing competition in the market. In sum, excess capacity has a dual effect and the observed effect can be considered as the net outcome of the two opposing effects. The estimated coefficient is positive and highly significant, showing that excess capacity tends to increase the degree of market power. The ONC was designed to deal with competition from coal imports, in particular dumping by German coal producers. Collusive strategies existed in the Belgian coal industry beginning in 1929 and involved all Belgian collieries from 1935 up to 1942. In order to test the possible effect of these strategies on the degree of market power, the binary variable $D3541_t$ was included in specification (A). The estimated coefficient is positive and significant at the 5% level. This result does not contradict the hypothesis that collusion in the Belgian coal industry was quite effective in 1935-41.

The economic cycle component

The third component of the domestic supply function encompasses the specification of the economic cycle. First, we used a basic approach through a binary variable that only considers the trend of the economic cycle (i.e. upward/downward). In specification (A), the estimated coefficient is significant and negative. This does not contradict the results derived by Haltiwanger and Harrington (1991): the collusion price is reduced when demand follows a downward trend.

The previous approach has a major shortcoming because it does not distinguish between high and low demand. In order to take account of the level of coal demand as well as its trend, we now consider the binary variables presented in Table 2. This leads to the definition of four specific cyclical states. On the whole, three results can be underlined. First, each significant coefficient associated with the three binary variables $DBH1_t$, $DCL1_t$ and $DCH1_t$ is negative. The collusive price is lowered when demand keeps growing and also when it follows a declining trend. Second, for specification (B), the classification by decreasing order of binary variables based on the absolute values of the estimates yields the following sequence: $DCH1_t$, $DCL1_t$ followed by $DBH1_t$. This result suggests that the incentive to reduce the collusive price is stronger in the decreasing part of the demand cycle and it reaches its climax in the second part of the downswing (i.e. when demand becomes very low). Thus, most of the estimates suggest that the negative impact of $DCL1_t$ on the collusive price is stronger than that of $DBH1_t$. This result does not contradict Haltiwanger and Harrington (1991, p. 98), who state that "(...) firms find it most difficult to collude when demand is declining, and this results in systematically lower prices during recessions than during booms." Further, the incentive to reduce the collusive price is reinforced as demand continues declining. This stems from two structural characteristics of the extractive industries: high fixed costs and the need to maintain regular exploitation of the coal veins. Collieries are particularly sensitive to any demand reduction because of these constraints. When demand falls, collieries are therefore prompted to cut their prices in order to maintain the level of their sales. Consequently, the lower the demand level, the greater the incentive to cut prices.

Statistical tests show that the estimates are free of serial correlation of residuals. Further, a Sargan-Hansen test was implemented to test for exogeneity of instruments and a test derived from Hausman (1978) was applied in order to check for exogeneity of the explanatory variables.[40]

[40] Table 4 presents the probability associated with the J statistics for the Sargan-Hansen test and the χ^2 statistics for the Hausman test. The null hypothesis of the Sargan-Hansen test is that the instruments are exogenous, while the null hypothesis of the Hausman test is that the three equations of the system are correctly specified. In specifications (A) and (B), both probabilities are higher than 1% so both null hypotheses are not rejected.

TABLE 6
The relationship between the Lerner index and real GDP*

	Specification 1			Specification 2			Specification 3		
	Coef.	Std. err.	P > |Z|	Coef.	Std. err.	P > |Z|	Coef.	Std. err.	P > |Z|
Constant	0.104	4.145E-2	0.0161	0.139	3.884E-2	0.0000	0.131	3.826E-2	0.0014
$RGDPBEL_t$ * $D0128_t$	1.494E-4	1.850E-4	0.4241	-	-	-	-	-	-
$RGDPBEL_t$ * $D2934_t$	-	-	-	-1.930E-4	1.907E-4	0.3177	-	-	-
$RGDPBEL_t$ * $D3538_t$	4.606E-4	2.430E-4	0.0652	-	-	-	4.338E-4	2.157E-4	0.0511
$RGDPBEL_t$ * $D3541_t$	-	-	-	4.576E-4	1.752E-4	0.0126	-	-	-
$RGDPBEL_t$ * $D3941_t$	-	-	-	-	-	-	5.545E-4	2.641E-4	0.0421
Market $power_{t-1}$	0.603	0.126	0.0000	0.514	0.125	0.0002	0.529	0.125	0.0001
R^2	0.41			0.47			0.46		
Number obs.	44			44			44		
Ljung-Box (2 lags)	0.689			0.847			0.882		
Ljung-Box (10 lags)	0.674			0.276			0.389		
Ljung-Box (20 lags)	0.113			0.015			0.039		
BG test (1 lag)	0.688			0.899			0.757		
BG test (4 lags)	0.451			0.698			0.691		
Cum. period. test	0.0859			0.0920			0.0960		

* The Z statistics are not shown for reasons of space. The dummy D0128 is equal to 1 in 1901-28 and 0 otherwise. A similar interpretation applies for other dummies.

An annual record of the marginal cost of production was constructed by using specification (B). This was combined with the series of real coal prices in order to compute an annual indicator of the Lerner index. In order to examine the time-varying relationship between market power and real GDP, linear regressions were estimated in which the market power indicator is explained by period dummy variables interacted with real GDP.

In the period 1901-28, the estimates are insignificant, which is consistent with the absence of any significant collusive strategies in the Belgian coal industry up to 1928. The same goes for 1929-34, while a collusive structure existed from 1929 on. The insignificant coefficient is probably due to the Liège coal basin's non-adherence to the cartel, which limited the cartel's effectiveness. The estimates obtained for the periods 1935-38, 1939-41 and 1935-41 paint a different picture, with a significant alteration of the relationship between the economic cycle and the Lerner index. These results indicate an increase in the cartel's efficiency, in its ability to alter the influence of the economic cycle on the Lerner index.

5. Conclusion

Three main results are to be underlined. They are in line with the objectives stated in the introduction.

First, this article has shown the effectiveness of the collusive structure developed in the Belgian coal industry by the end of the 1920s and reinforced in the mid-1930s. More specifically, the collusive strategies were a rational reaction to the intense competition of foreign coal producers, especially the German and Dutch collieries. Our estimates indicate that there were significant changes in the correlation coefficient between the market power indicator and Belgian real GDP from 1935. This can be read as a sign of the effectiveness of the cooperative structure created in 1928 and reinforced in 1935. The Belgian coal industry benefited from a higher price-cost margin during the second half of the 1930s, due to the strengthening of cooperative strategies enabled by the creation of the ONC, despite its relative weakness.[41] However, this improvement in the price-cost margin was not solely the result of cartelisation. Other factors certainly played a significant role. One was the cyclical improvement in the Belgian economy in the mid-1930s. Another was state intervention in the coal industry in the form of financial subsidies on the one hand and limits on coal imports, by means of quotas and duties, on the other.

Second, the econometric results do not contradict those derived in Haltiwanger and Harrington (1991) regarding the effect of the business cycle on firms' ability to sustain cooperation. Moreover, several results derived from that model have been corroborated through the estimates.

The third result is a direct application of the non-rejection of the model of Haltiwanger and Harrington (1991). The estimates obtained here indicate that the path of collusive prices anticipates the economic cycle. Firms are less apt to collude when demand is declining. This result implicitly suggests that competition authorities should intensify their controls on an industry when demand begins to grow.

This analysis could be refined in various ways. The economic cycle's effects on collusive conduct could be captured in part on an infra-annual basis.[42] The use of monthly data could shed light on these infra-annual phenomena. The present paper has established the usefulness of the demand cycle as a tool to detect collusive conduct. This problematic could be enriched through the use of financial data so as to infer information on collusive behaviour within an industry.

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[41] This result rests on the positive sign of the coefficient associated with the $D3541_t$ binary variable in specification (A) as well on the fact that both annual Lerner indices computed on the basis of estimated specifications (A) and (B) exhibit higher levels between 1935 and 1941.

[42] According to Haltiwanger and Harrington (1991), the collusive price path should anticipate the demand path. It has not been possible to show this with the annual data. This could be due to the fact that the phenomenon appears on an infra-annual basis which cannot be captured in the year-by-year database used here.

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Appendix

A.1. Data on productivity

TABLE 7
Daily productivity per capita for underground miners and surface workers

Area	1913	1920	1924	1930	1936	1937	1938
Upper Silesia	1.139[a]	0.635[a]	0.933[a]	1.454[b]	1.897[b]	1.924[b]	1.860[b]
Great Britain	1.032[a]	0.743[a]	0.872[a]	1.100[b]	1.200[b]	1.185[b]	1.158[b]
Ruhr coal basin	0.943[a]	0.626[a]	0.852[a]	1.352[b]	1.711[b]	1.627[b]	1.550[b]
Netherlands	0.820[a]	0.582[a]	0.733[a]	1.246[b]	1.787[b]	1.774[b]	1.750[b]
Poland	1.202[a]		0.728[a]	1.360[b]	1.845[b]	1.823[b]	1.817[b]
France	0.701[a]	0.475[a]	0.548[a]	0.694[b]	0.858[b]	0.833[b]	0.832[b]
Belgium - Southern coal basin	0.538[c]	0.479[c]	0.462[d]	0.572[b]	0.731[b]	0.724[c]	0.699[c]
Belgium - Limbourg coal basin			0.343[e]	0.609[b]	1.131[b]	1.083[e]	1.035[e]

Notes: Productivity data are based on the net production of coal in tons. The Limbourg coal district did not start producing until 1917; data are not available for 1913 and also for 1920, but in 1921 daily productivity per head was 0.248. No data are available for Poland in 1920. Sources: (a) Heaulme (1948, p. 216); (b) *Bulletin de l'Institut de Recherches Économiques*, no. 2, February 1939, p. 152; (c) Baudhuin (1946, p .15); (d) Coppé (1940, p. 102); (e) Baudhuin (1946, p. 19).

The data sources and the methodology used to construct each index used in the empirical analysis are detailed in sections A.2 to A.12 below.

A.2 The price

The annual price series for Belgian coal in terms of the value per ton of output is taken from the periodical *Annales des Mines de Belgique*. Data on the sales price of the coal ore, taken from the same source, are only available from 1913 to 1945. However, the correlation coefficient of these two series is higher than 0.99, so the price series for the ore extracted can be considered an excellent proxy for the sales price series.

In order to obtain a real price series, the price in the energy industry was used as a deflator. The latter was taken from Van Meerten (2003, p. 368ff).

A.3 Imports and exports

Data on Belgian coal imports were gathered from three main sources. for the periods 1901-13 and 1919-20, from various issues of the periodical *Annales des Mines de Belgique*; for the period 1914-18, from a graph in the periodical *Bulletin de l'Institut des Sciences Economiques*, vol. 3, 1931-1932, pp. 176-177; for the period 1921-45, from various issues of the French periodical *Annales des Mines*. This variable corresponds to Q_t^i and only refers to coal product, not coke nor briquettes. The same sources were used to collect data on coal exports.

A.4 Coal production

To gauge the annual demand for coal in the Belgian market, the coal sales of all Belgian coal districts were added to the amount of coal imported. In order to focus on the domestic demand for coal, the amount of exported coal was then subtracted from this result. All the variables considered here are measured in tons of coal. This variable corresponds to Q_t^m. Data on coal sales were obtained from various issues of the *Annales des Mines de Belgique*. This variable only refers to coal product, not coke nor briquettes.

A.5 Stocks

Data on coal stocks were obtained from the *Annales des Mines de Belgique*. This corresponds to the $STOCK_t$ index. These stocks are measured at the end of each year.

A.6 Excess production capacity

Data on excess production capacity were constructed following a method provided by Henley (1988). The total gross coal production of Belgium was used as the raw statistical material to construct an annual series of excess capacity. It was presumed that the first year of the period considered, 1901, corresponded to full use of production capacity. Next, point A_t was selected in the series of coal production in order to maximize the slope of the line between the initial point and point A_t. Coal production capacity is then measured from 1901 to year *t*. The same methodology was applied to the whole period to obtain a $CAPACITY_t$ series. In order to measure excess production capacity, the difference between coal production capacity and coal production was measured for each year. Hence the $CAPA2_t$ index which takes fully into account large excess capacities associated with WW1.

A.7 GDP

Data on the real GDP indices of Belgium, Germany, the United Kingdom, France and the Netherlands were obtained from Maddison, *L'économie mondiale 1820-1992*, 1995, p. 160ff. These variables correspond to $RGDPBEL_t$, $RGDPGER_t$, $RGDPUK_t$, $RGDPFR_t$ and $RGDPNED_t$ respectively.

A.8 Wages

Data on the nominal wages of miners at the coalface come from the periodical *Annales des Mines de Belgique*. This series is expressed in real terms with the same method as above. This variable corresponds to $RGWV_t$.

A.9 The interest rate

The nominal interest rate data were taken from Homer (1963, pp. 456-457). The Belgian official discount rate published in the same reference was used. Data for 1913 were not available; the gap was filled by linear interpolation between 1912 and 1914.

A.10 The economic cycle

The economic cycle was modelled using two complementary approaches. The first is simpler in that it considers only the slope of total coal production in Belgium (coke and briquettes excluded) $TOTALQ_t$. This method was used in Rosenbaum and Sukharomana (2001). The trend component of the total coal production series was isolated through exponential smoothing. Next, the $DQTOTALEES_t$

dummy was defined as follows. When the trend component of $TOTALQ_t$ is increasing (decreasing), then $DQTOTALEES_t$ is 0 (1).

The second approach is richer because it takes into consideration the slope (positive or negative) of the economic cycle as well as its level (high or low). More specifically, the coal production capacity series was taken into account, after being constructed with the methodology explained in A.6. An annual index of coal capacity production was computed using ($UCAPACITY_t$) as, $QTOTAL_t / UCAPACITY_t$ where $QTOTAL_t$ is the Belgian coal production series and $CAPACITY_t$ is Belgian coal production capacity. The mean value of the $UCAPACITY_t$ index for the period 1901-1945 was computed in order to have a benchmark for fixing the arbitrary values k_1 and k'_1.

In order to distinguish between a boom phase and a crisis phase, it is necessary to distinguish between the first difference of the $UCAPACITY_t$ index: $\Delta_t = UCAPACITY_t - UCAPACITY_{t-1}$. A boom phase (crisis phase) corresponds to an upward (downward) trend of capacity use. With the previous notations, a boom phase (crisis phase) is defined by $\Delta_t > 0$ ($\Delta_t < 0$).

By combining the sign of the first difference with the level of the $UCAPACITY_t$ index relative to the k_1 parameter, four dummies are defined as follows:

(a) $\Delta_t > 0$ and $UCAPACITY_t < k_1$ ==> $DBL1 = 1$ while $DBH1 = DCL1 = DCH1 = 0$;
(b) $\Delta_t > 0$ and $UCAPACITY_t > k_1$ ==> $DBH1 = 1$ while $DBL1 = DCL1 = DCH1 = 0$;
(c) $\Delta_t < 0$ and $UCAPACITY_t > k'_1$ ==> $DCL1 = 1$ while $DBL1 = DBH1 = DCH1 = 0$;
(d) $\Delta_t < 0$ and $UCAPACITY_t < k'_1$ ==> $DCH1 = 1$ while $DBL1 = DBH1 = DCL1 = 0$.

With: $DBL1$: Dummy for a boom period with low demand;
$DBH1$: Dummy for a boom period with high demand;
$DCL1$: Dummy for a crisis period with high demand;
$DCH1$: Dummy for a crisis period with low demand.

These four dummies allows us to formalise four specific states of the economic cycle.[43]

A.11 Oil price

$OIL\_PRICE\_BEF_t$ is constructed based on annual data of crude oil prices in USD retrieved online from *BP stat review*.[44] These data, expressed in real terms, were converted into Belgian francs. A yearly assessment of the USD-BEF exchange rate was obtained with a method based on the PPP theory. Annual indices of consumer prices in the United States and Belgium were used.[45] Despite its lack of precision, this method permits construction of an annual series of the USD-BEF exchange rate.

A.12 Other binary variables

The dummies $D14_t$, $D21_t$, $D29_t$, $D37_t$ and $D38_t$ are equal to one in 1914, 1921, 1929, 1937 and 1938 respectively. The dummies $WW1_t$ and $WW2_t$ are equal to one in 1914-1918 and 1939-1945 respectively. The dummy $D3541_t$ is equal to one in 1935-1941 and a similar interpretation applies for $D0128_t$, $D2934_t$, $D3538_t$ and $D3941_t$. Finally, the $QUOTAS_t$ binary variable represents the imposition of coal import quotas in Belgium from 1931, a policy that lasted until 1939. This binary variable is equal to one in 1931-39.

A.13 The unit root tests

First, we tested the unit root hypothesis on each of the variables with the test of Ng and Perron (2001). Most of variables tested are stationary in level; six appear non-stationary in level.

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43 Several sets of binary variables were constructed, but in Table 4 only one set of binary variables is presented. This unique set corresponds to $i = 1$. Specifically, $\overline{UCAPACITY}_t = 0.918$ in 1901-1945, with $(k_1; k_1') = (0.94; 0.94)$.

44 www.bp.com/content/dam/bp/en/corporate/excel/energy-economics/statistical-review/bp-stats-review-2018-all-data.xlsx.

45 The CPI for United States was obtained from https://www.minneapolisfed.org/community/financial-and-economic-education/cpi-calculator-information/consumer-price-index-1800. The CPI for Belgium was constructed from a graph available in J. Annaert et al. (2011).

TABLE 8
Ng and Perron (2001) unit root tests

Variable	Model	MZ_{α}^{GLS}	MZ_{t}^{GLS}	MSB^{GLS}	MP_{T}^{GLS}
Q_t^m	T	-606.690***	-17.394***	0.0286***	0.1866***
Q_t^i	I	-7.5987*	-1.8885*	0.2485*	3.4461*
Q_SALES$_t$ (i.e. Q_t^d)	T	-50.377***	-4.922***	0.098***	2.280***
P_t^r	I	-12.0849**	-2.3355**	0.1932**	2.4956**
RGDPBEL$_t$	T	-11.9318	-2.3849	0.1998	7.9417
RGDPGER$_t$	T	-7.6542	-1.9021	0.2485	12.029
RGDPNED$_t$	T	-27.1121***	-3.4153**	0.1259***	4.8700**
P_t^r x MINERS$_t$	I	-6.8412*	-1.6276*	0.2379*	4.3169*
P_t^r x OIL_PRICE_BEF$_t$	I	-12.9699**	-2.4621**	0.1898**	2.2122**
MINERS$_t$	T	-13.6697	-2.4369	0.1782*	7.6513
OIL_PRICE_BEF$_t$	I	-14.6243***	-2.5927***	0.1773**	2.0923**
DIFFBELNED$_t$	T	-1.8200	-0.4534	0.2491	22.2880
DIFFBELFR$_t$	T	-4. 0212	-1.0074	0.2505	18.4597
I_RATE$_t$	I	-7.4751**	-1.8273**	0.2444**	3.6577**
RGWV$_t$	I	-11.7259**	-2.4162**	0.2060**	2.1097**
CAPA2$_t$	T	-15.0704	-2.7146	0.1801*	6.2255*
STOCK$_t$	T	-16.0551*	-2.7537*	0.1715*	6.1466*
Critical values					
Model I: Intercept					
1%		-13.8	-2.58	0.174	1.78
5%		-8.1	-1.98	0.233	3.17
10%		-5.7	-1.62	0.275	4.45
Model T: Trend & intercept					
1%		-23.8	-3.42	0.143	4.03
5%		-17.3	-2.91	0.168	5.48
10%		-14.2	-2.62	0.185	6.67

Note: The symbols *, ** and *** stand for rejection of the null hypothesis of unit root at 10%, 5% and 1% respectively. Critical values were obtained from Ng and Perron (2001, p. 1524). The lag to compute the test was chosen using the AIC criterion. The test is based on two models: one with only an intercept (model I) and one with a trend and an intercept (model T).

In order to complete this investigation, the stationary test of Kwiatkowski et al. (1992) was used. It indicated that all series are stationary in level. A major shortcoming of these two tests is that they do not take account of the presence of a structural change in the series.

TABLE 9
KPSS stationarity tests

Variable	Model	
Q_t^m	T	0.1059
Q_t^i	T	0.1101
Q_SALES_t (i.e. Q_t^d)	T	0.0954
P_t^r	T	0.1716**
$RGDPBEL_t$	T	0.1001
$RGDPGER_t$	T	0.1587**
$RGDPNED_t$	T	0.1453
P_t^r x $MINERS_t$	T	0.1685**
P_t^r x $OIL\_PRICE\_BEF_t$	I	0.6146**
$MINERS_t$	I	0.2364
$OIL\_PRICE\_BEF_t$	I	0.6084**
$DIFFBELNED_t$	T	0.1594**
$DIFFBELFR_t$	I	0.2545
I_RATE_t	I	0.3636
$RGWV_t$	I	0.2040
$CAPA2_t$	I	0.0953
$STOCK_t$	T	0.1005
Critical values		
Model I: Intercept		
1%	0.739	
5%	0.463	
10%	0.347	
Model T: Trend and intercept		
1%	0.216	
5%	0.146	
10%	0.119	

Note: The symbols *, ** and *** stand for rejection of the null hypothesis of stationarity at 10%, 5% and 1% respectively. The number of lags are selected with the Schwert (1988, p. 7) criterion for yearly data: Int [4 $(T/10)^{1/4}$], where Int is the integer function and T is the number of years. With T = 45, the number of lags is equal to 5.

According to Perron (1989), the standard tests of the unit root hypothesis may not be reliable in the presence of structural changes. This feature might explain the result obtained for six series with the unit root test of Ng-Perron, as all six have structural breaks.

In order to check the validity of these results, we applied another unit root test that includes the presence of a structural break in the series. The break date is determined endogenously within the test. The results presented in Table 10 below indicate that nearly all the series are level-stationary. However, the $MINERS_t$ series is signalled as non-stationary.

TABLE 10
ADF with break

Variable	Trend	Break	Break type	Break date	t_{ADF}
Q^m_t	T & I	T	IO	1940	-5.3513***
Q^i_t	T & I	T & I	IO	1936	-5.8475***
Q_SALES_t (i.e. Q^d_t)	T & I	T & I	IO	1933	-5.3021**
P^r_t	T & I	T	IO	1922	-4.6577**
$RGDPBEL_t$	I	I	AO	1916	-4.3786*
$RGDPGER_t$	T & I	T & I	IO	1928	-5.9212***
$RGDPNED_t$	T & I	I	AO	1935	-4.7938*
P^r_t x $MINERS_t$	T & I	T & I	IO	1918	-5.5374**
P^r_t x $OIL\_PRICE\_BEF_t$	T & I	I	IO	1940	-6.0369***
$MINERS_t$	I	I	IO	1918	-2.7477
$OIL\_PRICE\_BEF_t$	T & I	I	IO	1940	-8.0931***
$DIFFBELNED_t$	I	I	AO	1919	-7.97235***
$DIFFBELFR_t$	T & I	T & I	IO	1938	-5.2699**
I_RATE_t	T & I	T & I	IO	1924	-6.2290***
$RGWV_t$	I	I	AO	1917	-4.8074**
$CAPA2_t$	T & I	T	IO	1944	-6.3383***
$STOCK_t$	T & I	T & I	IO	1929	-7.4028***
Critical values					
Trend	**Break**	**1%**	**5%**	**10%**	
T & I	T & I	-5.7191	-5.1757	-4.8939	
T & I	T	-5.0674	-4.5248	-4.2610	
T & I	I	-5.3475	-4.8598	-4.6073	
I	I	-4.9491	-4.4436	-4.1936	

Note: The symbols *, ** and *** stand for rejection of the null hypothesis of unit root at 10%, 5% and 1% respectively. The lag to compute the test was chosen using the AIC criterion.

Visual examination of the $MINERS_t$ series highlights the presence of not one but two structural breaks. In order to test this hypothesis, we used the test of Bai and Perron (2003). Following Kejriwal and Lopez (2013), the test considers a maximum of two breaks.

TABLE 11
Bai-Perron test

Variable	Break test hyp.: 0 vs. 1		Break test hyp.: 1 vs. 2		Result
	F-statistic	Critical value	F-statistic	Critical value	
$MINERS_t$	26.81	8.58	29.67	10.13	2 breaks

Note: Critical values have been computed by Bai and Perron (2003). For example, given that for $MINERS_t$ the computed F-statistic is equal to 26.81 while the critical value is 8.58, this points to the presence of a break in the series at 5% of risk. The same procedure is applied to test the hypothesis of two breaks in the series.

The results presented in Table 11 above indicate the presence of two breaks. The problem with the previous unit root test presented in Table 10 is that it is limited to only one structural break. As a consequence, we considered the unit root test defined by Lee and Strazicich (2003), which make it possible to incorporate two structural breaks in the series. This test was applied only to the series that was signalled as non-stationary in level according to the previous unit root test, i.e. $MINERS_t$.

TABLE 12
Lee-Strazicich unit root tests

Variable	Model	Test statistic	Critical values			Break dates	
			1%	5%	10%	1st break	2nd break
$MINERS_t$	T & I	-5.7583**	-6.285	-5.665	-5.295	1912	1922

Note: ** denotes significance at 5%. The "T & I" model allows for changes in level and trend. The lag to compute the test was chosen using the AIC criterion.

On the basis of the previous statistical tests, we conclude that the $MINERS_t$ series is stationary in level. This result is underlined by the unit root tests that incorporate the presence of one or two structural breaks.

A.14 Annual indices and summary statistics

TABLE 13
Annual indices used in the econometric analysis

INDEX	DEFINITION
$CAPA2^t$	Excess production capacity of coal based on total gross production (in tons)
$D14^t$	Binary variable associated with the year 1914
$D21^t$	Binary variable associated with the year 1921
$D29^t$	Binary variable associated with the year 1929
$D38^t$	Binary variable associated with the year 1938
$D3541_t$	Binary variable associated with the existence of a collusive structure in 1935-1941
$DBH1_t$	Binary variable associated with a boom phase with high demand
$DBL1_t$	Binary variable associated with a boom phase with low demand
$DCH1_t$	Binary variable associated with a crisis phase with low demand
$DCL1_t$	Binary variable associated with a crisis phase with high demand
$DIFFBELFR_t$	Difference between Belgian real GDP and French real GDP
$DQTOTALEES^t$	Binary variable associated with a depression phase, i.e. equal to 1 (0) when the exponential smoothing of the $TOTALQ_t$ series is downward-(upward) sloping
I_RATE^t	Nominal interest rate of the Belgian official discount rate (in per cent)
$MINERS^t$	Total number of workers in Belgian collieries
$OIL\_PRICE\_BEF_t$	Real price of crude oil in Belgian francs
P^r_t	Real price of coal (in Belgian francs)
Q_SALES_t	Residual demand for coal from Belgian collieries ($Q^d_t = Q^m_t - Q^i_t$)
Q^i_t	Coal imports in Belgium
Q^m_t	Total demand for coal
$QUOTAS_t$	Binary variable associated with the imposition of coal import quotas in 1931-1939
$RGDPBEL_t$	Index of real GDP of Belgium (1913 =1 00)
$RGDPFR_t$	Index of real GDP of France (1913 = 100)
$RGDPGER_t$	Index of real GDP of Germany (1913 = 100)
$RGDPNED_t$	Index of real GDP of the Netherlands (1913 = 100)
$RGDPUK_t$	Index of real GDP of the United Kingdom (1913 = 100)
$RGWV_t$	Real gross wage at the coalface (in real Belgian francs)
STOCKt	Stocks of coal in Belgium (in tons)
$TIME_t$	The linear temporal trend
$TOTALQ_t$	Total coal production in Belgium (coke and briquettes excluded)
$UCAPACITY_t$	Index of coal production capacity use
$WW1_t$	Binary variable associated with World War 1, 1914-1918
$WW2_t$	Binary variable associated with World War 2,1939-1945

TABLE 14
Summary statistics

Name	Mean	St. Dev.	Minimum	Maximum
P_t^r	1.35	0.16	1.09	1.74
Q_t^i	4564039.19	3382444.63	0.00	11375000.00
Q_t^m	18351053.61	5111109.87	9698437.28	28901310.00
Q_SALES_t (i.e. Q_t^d)	13787014.42	3353266.98	7914065.00	21771030.00
I_RATE_t	4.10	1.44	2.00	7.50
$CAPA2_t$	1984412.89	2511506.25	0.00	8626747.14
$STOCK_t$	1108141.84	865229.89	120420.00	3610790.00
$MINERS_t$	137772.78	18290.73	89007.00	174138.00
$TIME_t$	23.00	12.99	1.00	45.00
$RGDPBEL_t$	103.73	16.53	67.80	133.60
$RGDPGER_t$	106.90	33.92	66.80	188.70
$RGDPNED_t$	127.72	38.19	72.90	195.10
$DIFFBELFR_t$	4.12	10.17	-8.90	41.00
$DIFFBELNED_t$	-23.99	24.15	-61.50	12.00
$RGWV_t$	0.44	0.05	0.28	0.55
$OIL\_PRICE\_BEF_t$	80.49	76.56	15.17	316.42
P_t^r*$MINERS_t$	187865.12	43092.17	96892.70	288124.77
P_t^r*$OIL\_PRICE\_BEF_t$	103.90	88.72	17.43	384.98