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The global markets for coking coal and iron ore — Complementary goods, integrated mining companies and strategic behavior☆

Harald Hecking, Timo Panke *

Institute of Energy Economics, University of Cologne, Vogelsanger Strasse 321, 50827 Cologne, Germany

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A B S T R A C T

The global market for coking coal is linked to the global market for iron ore since both goods are complementary inputs in pig iron production. Moreover, international trade of both commodities is highly concentrated, with only a few large companies active on both input markets. Given this setting, the paper presented investigates the strategy of quantity-setting (Cournot) mining companies that own both a coking coal and an iron ore division. Do these firms optimize the divisions' output on a firm level or by each division separately (division-by-division)? First, using a theoretical model of two Cournot duopolies of complementary goods, we find that there exists a critical capacity constraint below/above at which firm-level optimization results in identical/superior profits compared with division-level optimization. Second, by applying a spatial multi-input equilibrium simulation model of the coking coal and iron ore markets, we find that due to the limited capacity firms gain no (substantial) additional benefit from optimizing output on a firm level.

1. Introduction

The research presented in the paper at hand is inspired by an important energy source that exhibits the characteristics of a complementary input factor: coking coal. Coking coal is a complementary input to iron ore for steel production. Both goods are indispensable when making crude steel using the so-called "oxygen route", i.e., first producing the pig iron in a basic oxygen furnace and, second, using the pig iron in a blast furnace to create the final product, crude steel. From an energy economics perspective, this industry example is of particular interest because (i) the goods are complements, (ii) each of the inputs is of little use in alternative applications (e.g., power plants typically use coals of different quality), (iii) international trading of both commodities is highly concentrated and (iv) only a few (large) firms are active in both input markets (parallel vertical integration), i.e., produce both coking coal and iron ore, with none of these firms being forward-integrated into the production of steel. Given this market setting, the paper presented investigates the strategy of Cournot-behaving mining companies that own both a coking coal and an iron ore division. Do these firms optimize the divisions' output on a firm level or according to each division separately (division-by-division)?

In order to answer this question, our analysis comprises two steps: First, we derive a stylized theoretical model to investigate the profitability of firm-level optimization in a setting with two homogeneous Cournot duopolies of complementary goods. In total, three firms are active in both duopolies: two firms each serve solely one of the markets and one firm serves both markets. The latter firm can either optimize both divisions' output separately or on a firm level. Comparing total profits of the integrated firm allows us to answer our research question from a theoretical point of view. We consider two cases: one with unlimited capacities and one incorporating a binding capacity constraint on one of the divisions' output.

The actual markets for coking coal and iron ore are, however, more complex as (i) both markets have more than two suppliers, (ii) there are multiple firms which are parallel vertically integrated, (iii) production costs are heterogeneous, (iv) both markets are spatial with multiple demand and supply regions and (v) several producers face a binding capacity constraint. We therefore, in a second step, develop and employ a numerical, spatial, multi-input oligopoly simulation model of the coking coal and iron ore market, calibrated with data from a unique data set for

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* Corresponding author.
E-mail address: timo.panke@ewi.uni-koeln.de (T. Panke).

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the years 2008 to 2010. We run the model for a range of assumed demand elasticities for the complementary product (pig iron) to assess the profits of the integrated companies in both cases, i.e., the optimization on a firm level or on a division level. Furthermore, we compare the simulation results of three specific market settings to the actual market outcomes: In addition to one perfect competition scenario, we assess one scenario assuming division-by-division optimization of all integrated firms and another one assuming firm-level optimization of the integrated companies' business units. We then assess which of these three scenarios best explains the actual market outcomes with regard to trade flows, production volumes and prices of the two commodities. Concerning trade flows, we use three statistical measures to evaluate which setting provides the best fit.

The theoretical model confirms that firm-level optimization is more beneficial compared with division-by-division optimization. However, if one of the divisions' production capacity is limited, we show that there exists a critical capacity constraint (i) below which optimization on a firm level and on a division level yield indifferent results, (ii) above which firm-level optimization is always beneficial and (iii) that becomes smaller with lower demand elasticity.

Applying the simulation model for the coking coal and iron ore market yields three main findings: First, the lower the pig iron demand elasticity is, the more profitable the firm-level optimization is compared with the division-level optimization for an integrated mining company. However, for demand elasticities lower than −0.5 to −0.6, the benefits of firm-level optimization tend to zero. Second, comparing simulation results and actual market outcomes for the years 2008 to 2010 with respect to trade flows, prices and production volumes, the scenario assuming perfect competition, other than the two scenarios that assume players to behave in a Cournot-manner, does not match actual market outcomes. Third, the scenario assuming division-level optimization provides a more consistent fit with actual market outcomes than the firm-level optimization scenario, although one scenario does not unambiguously dominate the other. Thus, no indication is found that mining companies integrated into coking coal and iron ore production have applied firm-level optimization during the years 2008 to 2010.

At least two explanations for this finding are possible: First, because of capacity constraints, firm-level optimization only generates additional profits compared with division-level optimization if demand for the final product (pig iron) is rather inelastic. Second, additional management costs (increased organizational and transactional costs) that go along with firm-level optimization may outweigh additional profits. Hence, division-level optimization may leave sources of profits untapped but can be the profit-optimizing strategy of a mining company integrated in both coking coal and iron ore production.

Our research is motivated by two strands of literature. The starting point is the seminal publication by Cournot (1838) concerning the theory of complementary oligopolies. More recent papers on the topic of strategic behavior and complementary goods were inspired by Singh and Vives (1984), who develop a duopoly framework that allows for the analysis of quantity- and price-setting oligopolies assuming goods to be substitutes, independent or complements. Building on Singh and Vives' finding, a whole body of literature emerged, devoting its attention to analyzing the problem of complementary monopolies under different setups. However, the setting in which we are interested is different from the ones assumed in most of the papers belonging to this strand of literature: In our setting, the supply of each complement is characterized by an oligopoly, i.e., there are few substitutes for each complement, whereas most of the papers belonging to the body of literature referred to above assume each complementary good to be produced by a monopolist. Salinger (1989) is the only one to use a similar setting as the one presented in this paper.

Second, research on market power coordination and interdependent demand is an important stream of empirical literature for this paper. Hagem et al. (2006), for example, analyze the interdependency of natural gas demand and demand for emission permits and how a dominant player in these markets can benefit from coordinating its market power. Similarly, Pineau et al. (2011) investigate the market power of power generators concerning the interdependent demand of peak-load and base-load electricity. Second, concerning empirical literature, two analyze on strategic behavior on the coking coal market have inspired our research: Graham et al. (1999) and Trüby (2013). Graham et al. (1999) simulate the coking coal trade for the year 1996 for several supply- and demand-side market power cases. Trüby (2013) analyzes different market structures such as Cournot or Stackelberg behavior of mining companies to find evidence of non-competitive behavior. Further empirical papers dealing with the analysis of coking coal and iron ore trading have been published (e.g., Toweh and Newcomb (1991), Labson (1997) or Fiuza and Tito (2010)). However, to the best of our knowledge, there has yet to be a publication that handles the strategic interaction between both markets or that applies the theory of complementary inputs to a real-world setting.

Consequently, this paper contributes to the literature in three ways: First, we add a new dimension to the existing literature on the strategic behavior of coking coal producers by taking into account the iron ore market and the complementarity of both goods in pig iron production. Second, we extend the literature on resource market simulations by developing a spatial multi-input equilibrium model that accounts for coking coal and iron ore as complementary inputs and enables the simulation of market power on a firm level. Third, we assess the strategic behavior of firms that produce both coking coal and iron ore, thereby specifically accounting for capacity constraints.

The remainder of this paper is structured as follows: Section 2 introduces our theoretical framework and establishes our theoretical findings. The third section presents the motivation for our industry example, explains the structure of the simulation model used to model the coking coal and iron ore market and describes the numerical data used in this study. Section 4 analyzes the results obtained from the model simulations. More specifically, Subsection 4.1 analyzes, from the perspective of individual firms, the impact of firm- versus division-level optimization on the firms' profits. Subsection 4.2 assesses which of the three scenarios best explains the actual outcomes of the coking coal and iron ore market. Subsection 4.3 briefly discusses the strategic implications of these findings. Finally, Section 5 concludes.

2. Quantity-setting complementary oligopolies

In the setting we are interested in, supply of each complement, coking coal and iron ore, is characterized by a quantity-setting (Cournot) oligopoly. Each of the two complementary goods is considered as homogeneous. Furthermore, the setting is characterized by the existence of a number of parallel vertically integrated firms, i.e., mining companies which produce both coking coal and iron ore.[1] Consequently, we model two simultaneous Cournot equilibria both of which influence the composite good's demand and thus the price of the two complementary goods. The approach chosen in this paper resembles the one in Salinger (1989), who uses a similar setting of complementary oligopolies to investigate how different definitions of the terms "upstream" and "downstream" change the impact of a vertical merger on competition. Following Salinger (1989), we assume players active in one input market to take the price of the other complement as given, thus we assume $\frac{\partial p_1}{\partial x_2} = \frac{\partial p_2}{\partial x_1} = 0$.

This assumption implies that we abstract from the "tragedy of the anticommons" problem. The problem was first described by Sonnenschein (1968), who pointed out the duality between a Bertrand duopoly with substitutes and a Cournot complementary monopoly. Sonnenschein (1968) showed for a setup in which each

[1] In reality there are steel companies which are backward-integrated. i.e., produce iron ore or coking coal. However, addressing this market structure would be beyond the scope of our research. In addition, these firms make up for only a small share of globally traded volumes of iron and coking coal. We explain how we dealt with this issue in footnote 10 in Section 3.3.2.