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AUTHORS

Harald Hecking
Timo Panke

EWI Working Paper No. 14/06

February 2014

Institute of Energy Economics at the University of Cologne (EWI)
www.ewi.uni-koeln.de

Institute of Energy Economics
at the University of Cologne (EWI)

Alte Wagenfabrik
Vogelsanger Str. 321
50827 Cologne

Tel.: +49 (0) 221 277 29-100
Fax: +49 (0) 221 277 29-400
www.ewi.uni-koeln.de

Corresponding Author

Timo Panke
Institute of Energy Economics at the University of Cologne (EWI)
Tel.: +49 (0) 221 277 29-202
Fax: +49 (0) 221 277 29-400
timo.panke@ewi.uni-koeln.de

ISSN: 1862-3808

Quantity-setting Oligopolies in Complementary Input Markets - the Case of Iron Ore and Coking Coal

Harald Hecking[a], Timo Panke[a,*]

[a] *Institute of Energy Economics, University of Cologne, Vogelsanger Strasse 321, 50827 Cologne, Germany.*

Abstract

This paper investigates the benefits of a merger when goods are complements and firms behave in a Cournot manner both in a theoretical model as well as in a real-world application. In a setting of two complementary duopolies a merger between two firms each producing one of the goods always increases the firms' total profit, whereas the remaining firms are worse off. However, allowing for a restriction on one of the merging firms' output, we proof that there exists a critical capacity constraint (i) below which the merging firms are indifferent to the merger, (ii) above which the merger is always beneficial and (iii) the lower the demand elasticity is the smaller this critical capacity constraint becomes. Using a spatial multi-input equilibrium model of the iron ore and coking coal markets, we investigate whether our theoretical findings may hold true in a real market as well. The chosen industry example is particularly well suited since (a) goods are complements in pig iron production, (b) each of the inputs is of little use in alternative applications, (c) international trade of both commodities is highly concentrated and (d) a few (large) firms are active in both input markets. We find that due to limited capacity, these firms gain no substantial extra benefit from optimising their divisions simultaneously.

Keywords: Cournot oligopolies, parallel vertical integration, complementary inputs, applied industrial organisation, mixed complementarity problem
JEL classification: C61, D43, L22, Q31, Q41.

1. Introduction

The research presented in the paper at hand is inspired by an interesting example of an industry with complementary inputs, namely iron ore and coking coal. Both goods are indispensable inputs

* Corresponding author:
Email address: timo.panke@ewi.uni-koeln.de, +49 221 27729202 (Timo Panke)

We would like to thank Felix Höffler for his helpful comments and suggestions. Furthermore we would like to thank Johannes Trüby for sharing his dataset on the coking coal market and Robert Germeshausen for providing excellent research assistance.

when making crude steel using the so-called ”oxygen route”, i.e., producing first 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. 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 differenty quality, (iii) international trade of both commodities is highly concentrated and (iv) a few (large) firms are active in both input markets (parallel vertical integration), i.e., produce both iron ore and coking coal, although none of them is vertically integrated in the production of steel. This market setting raises at least one important question: Do firms benefit from behaving parallel vertically integrated, or put differently, is a merger between two firms, where each of the firms produce a different complement, profitable?

In order to answer this question, our analysis comprises two steps: First, we use a simple theoretical model to investigate the profitability of a merger in a setting with complementary goods. In this model, we consider two homogeneous Cournot duopolies of complementary goods and assume the demand for the composite product to depend linearly on its price. We consider two cases, one with unlimited capacities and one incorporating a binding capacity constraint on one of the merging firms' output. Comparing total profits of the firms in a situation with or without a merger allows us to answer our research question from a theoretical point of view. The actual markets for iron ore and coking coal are however more complex as (i) both markets have more than two suppliers, (ii) there are multiple parallel vertically integrated firms, (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, second, develop and employ a spatial, multi-input oligopoly simulation model of the iron ore and coking coal market, calibrated with data from a unique data set for the years 2008 to 2010. We run the model for a range of assumed demand elasticities to assess profits of the integrated companies in both cases, i.e., the simultaneous (equivalent to the merger situation) and the separate optimisation (equivalent to the non-merger situation) of the business units. Further, we compare the simulation results of three specific market settings to the actual market outcomes. Besides one perfect competition scenario, we assess one scenario assuming separate optimisation of all integrated firms, and the other one assuming simultaneous optimisation of the integrated companies' business units. We then assess which of the 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 the result that a merger of two companies, each producing one of the complementary inputs, leads to higher profits than the sum of the two separate firm's profits. In other words, no merger-paradox exists when goods are complements and capacities are unconstrained. However, if one of the merging firms' capacity is limited, we prove that there exists a critical capacity constraint (i) below which merging is indifferent from not merging, (ii) above which the merger is always beneficial and (iii) the lower the demand elasticity is the smaller this critical capacity constraint becomes.

Applying the simulation model for the iron ore and coking coal market, we find that simultaneous optimisation (equivalent to the merger situation) generates additional benefits compared to separate optimisation (equivalent to the non-merger situation) the lower the assumed demand elasticity gets. However for demand elasticities beyond -0.5 to -0.6 the benefits of simultaneous optimisation tend to zero. Comparing simulation results and actual market outcomes for the years 2008 to 2010, no evidence of competitive behaviour on a firm level is found, which allows us to continue with the two Cournot scenarios. In terms of trade flows, prices and production volumes the separate optimisation scenario provides a more consistent fit with actual market outcomes than the simultaneous optimisation scenario although one scenario does not unambiguously dominate the other one. Taking into account low or zero extra benefits of simultaneous optimisation for the demand elasticities that yield the best fit, plus organisational and transactional costs of simultaneous optimisation, it is likely that integrated firms optimise their iron ore and coking coal divisions independently.

Our research is inspired by the extensive literature on the theory of complementary oligopolies, with the seminal publication by Cournot (1838) as a starting point. More recent papers on the topic of strategic behaviour and complementary goods were inspired by Singh and Vives (1984), who develop a duopoly framework that allows 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 analysing 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, supply of each complement is characterised by an oligopoly, i.e., there are few substitutes for each complement, while most of the papers belonging to the body of literature refered to above assume each complementary good to be produced by a monopolist. Salinger (1989) is among the few to use a similar setting as ours. In addition to the theoretical literature, several empirical papers have been published dealing with the analysis of iron ore and coking coal trading (e.g., Toweh and Newcomb (1991), Labson (1997), Graham et al. (1999) and Trüby (2013)) and the effects of mergers in the iron ore industry (Fiuza and Tito, 2010). However, to the best of our knowledge, there has not yet been a publication that deals with the strategic interaction between both markets and none applying the theory of complementary inputs to a real-world setting.

Consequently, this paper contributes to the literature in three ways: First, we provide insights into the effect of capacity constraints on the profitability of a merger between firms producing complementary goods and behaving in a Cournot manner. Second, this is the first study applying the theory of complementary quantity-setting oligopolies using the example of the iron ore and coking coal market. Third, we develop a spatial multi-input equilibrium model that has been calibrated using a unique data set for the years 2008-2010 and accounts for the complex interactions and the spatial nature of both markets, allowing us to simulate the exercise of market power on a firm level.

The remainder of this paper is structured as follows: Section 2 introduces our theoretical framework and establishes our theoretical findings. The third section motivates our industry example, explains the structure of the simulation model used to model the iron ore and coking coal market and describes the numerical data used in this study. Section 4 analyses the results obtained from the model simulations. More specifically, Subsection 4.1. analyses, from the perspective of individual firms, the impacts of simultaneous or separate optimisation on the firms' profits. Subsection 4.2. assesses whether price-taking behaviour or simultaneous or separate optimisation of the integrated firms best explains actual outcomes of the iron ore and coking coal 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 is characterised by a quantity-setting (Cournot) oligopoly, i.e., each of the two complementary goods is homogeneous. Furthermore, the setting is characterised by the existence of a number of parallel vertically integrated firms, i.e., companies which produce both complements. 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 complementary good is produced by one monopolist and each monopolist maximises its profit by choosing the optimal quantity of its good, an incentive arises to undercut total output of the other complement. In his setting an oversupply of one of the complements would cause its price to drop to zero (or to marginal costs if they are assumed to be greater than zero), leaving all the profits to the other complement's supplier. In the end, this would lead to a race-to-the-bottom in quantities. The unique Nash-equilibrium where such a deviation is not profitable is one where no firm produces at all. This somewhat paradox (and unrealistic) result relies heavily on the effect that even the slightest excess supply of one of the goods lets its price drop to zero. An effect which already Sonnenschein himself referred to as "somewhat obscure".[1] [2]

[1] This remark can be found in footnote 4 of Sonnenschein (1968).
[2] Another interesting aspect of complementary goods and Cournot competition was first brought forward by Singh and Vives (1984). They develop a duopoly framework that allows to analyse quantity- and price-setting oligopolies

Next, we first will quickly recall the market outcomes for the case of oligopolistic input markets, in which firms produce only one complement and compete by setting quantities and no capacity constraints exist. Second, we derive optimal quantities and prices in a setting that features one parallel vertically integrated firm, i.e. a firm that produces both complements. In Subsection 2.2, we first investigate if the introduction of a binding capacity constraint on one of the complementary goods of the parallel vertically integrated firm may change the favourability of a vertical merger. Second, we propose and proof three conjectures characterising the profitability of a merger.

2.1. A model of two complementary duopolies with no capacity constraints

To illustrate what effect parallel vertical integration, i.e., a merger between firms that produce different complementary goods, has on outcomes in a quantity-setting complementary oligopoly, we start out by considering a simple market that consists of four symmetric firms ($N = M = 2$) producing two complementary goods. Two firms (c_n) produce complement C (coking coal) and the remaining two firms (i_m) produce the other complement I (iron ore). Production costs are assumed to be zero. Complements I and C may be combined in fixed proportions (here: one unit each) to produce the composite good pi (pig iron), i.e., it holds true that $x_{pi} = x_i = x_c$ with $x_c = \sum_n^N x_c^n$ and $x_i = \sum_m^M x_i^m$. In addition, we assume full compatibility among the complements and perfect competition in the market for the composite good, such that NxM composite goods exist, all of which are available at price $p_{pi} = p_i + p_c$. Thus each complement's price ($p_i \left[\sum_m^M x_i^m, p_c\right]$ and $p_c \left[\sum_n^N x_c^n, p_i\right]$) depends on the supply of the complement ($\sum_m^M x_i^m$ or $\sum_n^N x_c^n$) as well as the price of the other complement. However, the price of the other complement is perceived as a cost component due to the assumption $\frac{\partial p_1}{\partial x_2} = \frac{\partial p_2}{\partial x_1} = 0$.

We also rule out that there is product differentiation in the composite good market, thus all NxM composite goods are perfect substitutes as well. Initially, we do not assume the compos-

(Bertrand, 1883) assuming goods to be substitutes, independent or complements. The two authors proof that in the case of a complementary monopoly companies prefer to offer price instead of quantity contracts, as this maximises their profits. Amongst other things, Häckner (2000) shows that this finding also holds true under more general assumptions including a setting with more firms (each producing one complementary good). In this paper both input markets are characterised by oligopolies with firms having production constraints. Therefore, if firms were assumed to engage in Bertrand competition and production capacity would be unconstrained prices of each complement would equal marginal costs and, thus profits would amount to zero. In the case of capacity constraints it has been shown that first-order conditions for profit maximisation may have a kink, such that equilibria may not be well defined. Therefore, companies would prefer quantity contracts over price contracts in our setting.

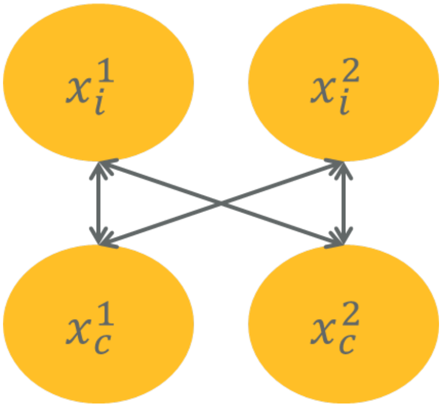

Figure 1: Market structure with independent ownership

ite good's inverse demand function to be of a specific functional form. Consequently, the profit functions of the four firms are given by

$$\Pi_{i_m} = p_i x_i^m \tag{1}$$

$$\Pi_{c_n} = p_c x_c^n. \tag{2}$$

Taking, for example, the first partial derivate of the profit function of firm i_1 yields the following first-order condition:

$$\frac{\partial \Pi_{i_1}}{\partial x_i^1} = p_i + \left(\frac{\partial p_i}{\partial x_i^1} \frac{\partial x_i^1}{\partial x_i^1} + \frac{\partial p_i}{\partial p_c} \frac{\partial p_c}{\partial x_i^1} + \frac{\partial p_i}{\partial x_i^{-m}} \frac{\partial x_i^{-m}}{\partial x_i^1} \right) x_i^1 = 0 \tag{3}$$

with x_i^{-m} being the iron ore production of the competitors. Due to the assumption that the firms engage in Cournot competition, it holds true that $\frac{\partial x_i^{-m}}{\partial x_i^1} = 0$. As discussed previously, in our model we assume that $\frac{\partial p_1}{\partial x_2} = \frac{\partial p_2}{\partial x_1} = 0$, hence Equation 3 simplifies to

$$\frac{\partial \Pi_{i_1}}{\partial x_i^1} = p_i + \frac{\partial p_i}{\partial x_i^1} \frac{\partial x_i^1}{\partial x_i^1} x_i^1 = 0. \tag{4}$$

In order to derive the market results we assume the demand function to be linear in form, i.e., $p_{pi} = a - bx_{pi}$. The first partial derivate of the profit function of firm i_1 yields the following first-order condition, which due to the assumed symmetry looks analogue for the other firms:

$$\frac{\partial \Pi_{i_1}}{\partial x_i^1} = p_i - bx_i^1 = 0. \tag{5}$$

Solving the resulting system of equations allows us to derive equilibrium output and prices under independent ownership:

$$x_{pi}^* = x_i^* = x_c^* = \frac{a}{2b}, \quad p_c^* = p_i^* = \frac{a}{4} \quad \text{and} \quad p_{pi}^* = \frac{a}{2}. \tag{6}$$

In order to illustrate the effects of parallel vertical integration, we now consider a setup in which one firm produces both complements, as depicted in Figure 2. The profit function of the parallel

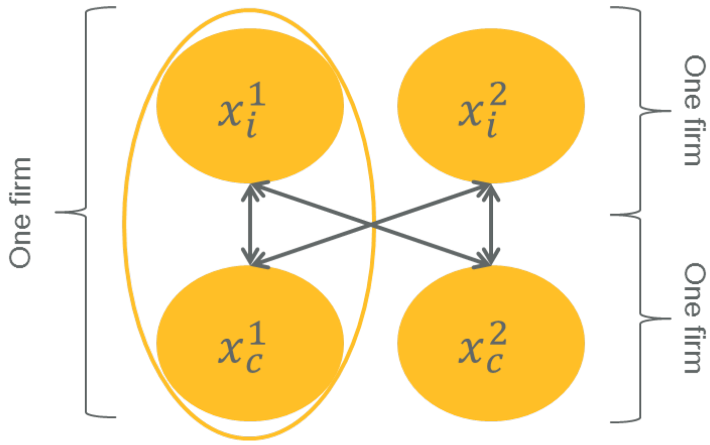

Figure 2: Market structure with one integrated firm

vertically integrated company (PVI), in its general form, i.e. without a specific functional form of the (inverse) demand function, is given by

$$\Pi_{PVI} = p_i x_i^{PVI} + p_c x_c^{PVI}. \tag{7}$$

Taking the first partial derivate of Equation 7 with respect to x_i^{PVI} and x_c^{PVI} yields:

$$\frac{\partial \Pi_{PVI}}{\partial x_i^{PVI}} = p_i + \left(\frac{\partial p_i}{\partial x_i^{PVI}} \frac{\partial x_i^{PVI}}{\partial x_i^{PVI}} + \frac{\partial p_i}{\partial p_c} \frac{\partial p_c}{\partial x_i^{PVI}} + \frac{\partial p_i}{\partial x_i^{-m}} \frac{\partial x_i^{-m}}{\partial x_i^{PVI}} \right) x_i^{PVI} + \frac{\partial x_c^{PVI}}{\partial x_i^{PVI}} p_c = 0 \tag{8}$$

$$\frac{\partial \Pi_{PVI}}{\partial x_c^{PVI}} = p_c + \left(\frac{\partial p_c}{\partial x_c^{PVI}} \frac{\partial x_c^{PVI}}{\partial x_c^{PVI}} + \frac{\partial p_c}{\partial p_i} \frac{\partial p_i}{\partial x_c^{PVI}} + \frac{\partial p_c}{\partial x_c^{-n}} \frac{\partial x_c^{-n}}{\partial x_c^{PVI}} \right) x_c^{PVI} + \frac{\partial x_i^{PVI}}{\partial x_c^{PVI}} p_i = 0. \tag{9}$$

We already know that $\frac{p_i}{x_c} = \frac{p_c}{x_i} = 0$ and $\frac{\partial x_i^{-m}}{x_i^m} = \frac{\partial x_c^{-n}}{x_c^n} = 0$. Keeping in mind that in this example a factor intensity (*fin*) of 1 is assumed, in case of a parallel vertically integrated firm $\frac{\partial x_c^{PVI}}{\partial x_i^{PVI}} = \frac{\partial x_i^{PVI}}{\partial x_c^{PVI}} = fin = 1$. Thus, an integrated firm knowing that an increase in one of the complements output needs an equally large increase of the other complement in order to increase the output of the composite good, would always find it beneficial to increase output of both goods at the same time. Assuming a linear inverse demand function of the composite good and using Equations 8 and 9, respectively, the resulting first-order conditions are:

$$\frac{\partial \Pi_{PVI}}{\partial x_i^{PVI}} = a - 2bx_i^{PVI} - bx_i^2 + p_c = p_i + p_c - bx_i^{PVI} = 0 \tag{10}$$

$$\frac{\partial \Pi_{PVI}}{\partial x_c^{PVI}} = a - 2bx_c^{PVI} - bx_c^2 + p_i = p_i + p_c - bx_c^{PVI} = 0. \tag{11}$$

Taking a closer look at the Equations 10 and 11, we see that due to the complementarity of the goods, in order to maximise its overall profits the parallel vertically integrated firm has to take into account not only the production of its direct competitors, but also the price of the complementary good. Solving again the resulting system equations allows us to derive equilibrium output and prices under parallel vertical integration:

$$x_{pi}^* = x_i^* = x_c^* = \frac{2a}{5b}, \quad p_c^* = p_i^* = \frac{a}{5} \quad \text{and} \quad p_{pi}^* = \frac{2a}{5}. \tag{12}$$

By comparing the equilibrium solutions, i.e., with (Equations 12) and without parallel vertical integration (Equations 6), we find that parallel vertical integration results in higher supply of the composite good and, therefore, of the two complementary inputs, which in turn leads to lower prices. Hence, a merger between two firms producing complementary goods increases consumer welfare.

Table 1: Market outcomes

	Independent ownership	**One parallel vertically integrated firm**
Price of composite good	$\frac{a}{2}$	$\frac{2a}{5}$
Price of complements	$\frac{a}{4}$	$\frac{a}{5}$
Quantity ($x_{pi} = x_i = x_c$)	$\frac{a}{2b}$	$\frac{3a}{5b}$
Each firm's output	$x_i^m = x_c^n = \frac{a}{4b}$	$x_i^{PVI} = x_c^{PVI} = \frac{2a}{5b}$ $x_i^2 = x_c^2 = \frac{a}{5b}$
Each firm's profit	$i^m = c^n = \frac{a^2}{16b}$	$PVI = \frac{4a^2}{25b}$ $\quad i_2 = c_2 = \frac{a^2}{25b}$

While consumers profit by the merger, the firms that are not part of the merger lose market share and make less profit. This is due to the fact that the merger effectively internalises a negative externality. The externality is negative due to the the fact that $\frac{\partial p_1}{\partial x_2} = \frac{\partial p_2}{\partial x_1} = 0$ (see also Salinger (1989)). If a company, producing one of the complements, chooses to reduce its output, the production of the composite good is reduced as well, thereby raising the composite good's price. This increases the price of the company's complement, while the other complement's price is not changed (because of $\frac{\partial p_1}{\partial x_2} = \frac{\partial p_2}{\partial x_1} = 0$). However, due to the reduction of the composite good's output, the output of the other complement is reduced. Consequently, reducing the output of one of the complements causes a negative externality on the firms producing the other complement. Consequently, the PVI company, internalising this negative externality, is willing to supply a larger amount of both inputs, which then leads to a reduction of the output of the remaining independent companies (see Table 1). Another interesting aspect is that, in contrast to Cournot oligopoly with substitutes and no capacity constraints, there is no merger paradox, i.e., profits of the new merged firm are always larger than the combined profits of the two single firms, again due to the internalisation of the negative externality.

Summing up, we recalled that a parallel vertically integrated company maximises its profits by optimising output of both goods accounting for the negative externality of reducing the output of one of the complements on the other. In the case with no capacity constraints, we showed that a merger between two firms producing different different complements is always profitable, i.e., it increases overall profit of the firms.

2.2. Profitability of a parallel vertical merger

As shown in Subsection 2.1, the profitability of a merger arises from increasing the integrated firm's output of both complements with respect to the case of independent ownership. Therefore, the question arises whether a constraint restricting the potential output of one of the two complements may alter the result that the merger is beneficial.

In order to do so, we need to recall from Subsection 2.1 that, first, an unconstrained integrated firm behaves in a manner similar to a Stackelberg leader, i.e. by taking into account the negative externality of the two complements, he increases his output compared to the case with no merger (see Table 1). Second, the integrated firm maximises its profit by supplying the same amount of both complements (in case of a factor intensity of both goods of 1), i.e. it provides both complements as a bundle. However, in case of a binding capacity constraint on one of the complements, the firm could also choose to supply different quantities of its two goods. Consequently, one can rewrite the profit function of the parallel vertical integrated firm from the previous subsection (Equation 7) as:

$$\Pi_{PVI} = (p_i + p_c)x_b + p_i x_i^{PVI} + p_c x_c^{PVI} \tag{13}$$

with x_b referring to the amount of bundled sales supplied to the market, thus it represents at the same time sales of iron ore as well as coking coal, while x_i^{PVI} and x_c^{PVI} need not be sold at a similar ratio. Thus the firm's total iron ore and coking coal output amounts to $x_b + x_i^{PVI}$ and $x_b + x_c^{PVI}$, respectively. In the following, using Equation 13 and a linear demand function, we would like to investigate the profitability of a merger in the event of a binding capacity constraint in more detail. Therefore, we propose three conjectures that we will proof subsequently:

Conjecture 1 *Given a specific linear demand function, there exists a critical capacity limit, $\overline{x}_b$, that causes the merging firms to be indifferent between the merger and not merging, i.e. profits do not change due to the merger. For capacity limits lower than $\overline{x}_b$ profits remain unchanged by the merger as well.*

Conjecture 2 *Given a specific linear demand function, for every capacity limit $\hat{x}_b$ that fulfills $\hat{x}_b > \overline{x}_b$, a merger is profitable despite a binding capacity constraint.*

Conjecture 3 *The less elastic the linear inverse demand function of the composite good, the lower becomes the critical capacity constraint, $\overline{x}_b$.*

Concentrating first on Conjecture 1, we need to show that for a given linear inverse-demand function of the composite good, there is a capacity limit to one of the complements $\overline{x}_b$[3] that causes the difference between the sum of the two separated firms' profits, $\pi_c^1 + \pi_i^1$, and the profit of the merged firm, π^{PVI}, to be zero. For this purpose, we start by deriving the equilibrium profit of PVI using the first-order conditions of the three firms (one integrated and two independent firms):

$$\frac{\partial \Pi_{PVI}}{\partial x_i^{PVI}} = -bx_i^{PVI} - bx_b + p_i = 0 \tag{14}$$

$$\frac{\partial \Pi_{PVI}}{\partial x_c^{PVI}} = -bx_c^{PVI} - bx_b + p_c = 0 \tag{15}$$

$$\frac{\partial \Pi_{PVI}}{\partial x_b} = -bx_b - bx_c^{PVI} - bx_i^{PVI} + p_c + p_i = 0 \tag{16}$$

Assuming a binding capacity constraint on the iron ore output of the integrated firm ($\overline{x}_b$), the first and third first-order conditions (Equations 14 and 16) will not be needed as the firm's optimal iron ore output is $\overline{x}_b$ (hence, $x_i^{PVI} = 0$), otherwise the capacity constraint would not be binding.

Knowing that the first-order conditions of the non-integrated firms remain unchanged (see Equation 10) and using $p_{pi} = p_i + p_c$ as well as Equation 15 yields

$$p_i = \frac{2a - 3b\overline{x}_b}{5}, \quad p_c = \frac{a + b\overline{x}_b}{5}, \quad x_c^{PVI} = -\frac{4}{5}\overline{x}_b + \frac{a}{5b}. \tag{17}$$

Therefore, the integrated firm's maximum profit function in case of a binding capacity constraint is

$$\pi^{PVI} = \frac{a^2 + 12ab\overline{x}_b - 14b^2\overline{x}_b^2}{25b}. \tag{18}$$

[3] We use x_b since if the capacity constraint on one of the complements is binding, the firm will choose to produce at least the same quantity of the other complement, hence it will supply $\overline{x}_b$-bundles.

We know from Subsection 2.1 that the profit of two unconstrained independent iron ore and coking coal firms amounts to $2 * \frac{a^2}{16b} = \frac{a^2}{8b}$ with each firm supplying $\frac{a}{4b}$ (see Table 1). In order to proof Conjecture 1, we thus need to show that when the capacity constraint is $\overline{x}_b = \frac{a}{4b}$ profits of the integrated firm equals the profits of the two independent firms:

$$\pi^{PVI} = \frac{a^2 + 12ab\frac{a}{4b} - 14b^2\left(\frac{a}{4b}\right)^2}{25b} = \frac{4a^2 - \frac{7a^2}{8}}{25b} = \frac{\frac{25a^2}{8}}{25b} = \frac{a^2}{8b}, \tag{19}$$

which is the case. Now, if we consider two independent firms with one of them being constraint in its output, e.g., the iron ore firm ($\overline{x}_i^2$), the function of the maximum profits is the same as in the case of no merger (see Appendix C). In other words, if the capacity limit equals the optimal quantity in the case of independent firms or is lower, profits of the firms remain unchanged by the merger, which is what we wanted to proof.

Regarding Conjecture 2, we need to show that for capacity constraints that are higher than $\overline{x}_b$ profits of the merged firms are higher than in the case of no merger. We already know that the optimal output of the unconstrained integrated firm is $\frac{2a}{5b}$. Taking a look at equilibrium output of x_c^{PVI} stated in Equation 17, we see that x_c^{PVI} is zero for $\hat{x}_b > \frac{a}{4b}$, because output in this model is restricted to be non-negative. Therefore, total output of the integrated firm is equal to $\hat{x}_b$ for $\hat{x}_b > \overline{x}_b = \frac{a}{4b}$. In this case, equilibrium prices and the integrated firm's profits are given by

$$p_i = p_c = \frac{a - b\hat{x}_b}{3}, \quad \pi^{PVI} = \frac{2a\hat{x}_b - 2b\hat{x}_b^2}{3} \quad \text{for } \hat{x}_b > \overline{x}_b. \tag{20}$$

Hence, for $\hat{x}_b > \overline{x}_b$ it holds true that the profits of the integrated firm change by

$$\frac{\partial \pi^{PVI}}{\partial \hat{x}_b} = \frac{2a - 4b\hat{x}_b}{9} \quad \text{for } \hat{x}_b > \overline{x}_b, \tag{21}$$

with $\frac{\partial \pi^{PVI}}{\partial \hat{x}_b} > 0$ for $\frac{a}{4b} < \hat{x}_b < \frac{2a}{5b}$, which proofs Conjecture 2. Figure 3 illustrates the profits of the integrated and two independents firms depending on the iron ore capacity.

Focussing now on Conjecture 3, we would like to show that the steeper the inverse demand function the lower the optimal quantities supplied in case of no merger $\frac{a}{4b}$ (see Table 1) and thus

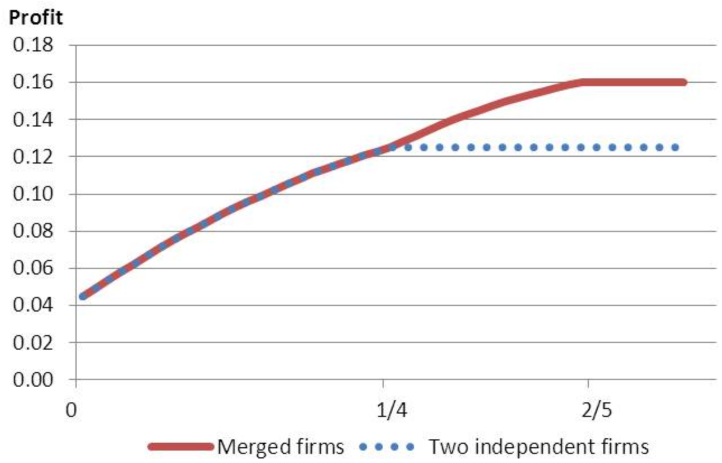

Figure 3: Profits of the integrated versus two independent firms

the lower the capacity constraint that renders the profits of an integrated and two non-integrated firms equal. Therefore, we need to establish the relationship between the ratio of a, the maximum willingness-to-pay, and b, the slope of the inverse demand function, and the assumed (absolute) point elasticity ϵ. Since it can be easily shown that a and b in the linear demand case can be written as:

$$a = p_{ref} + b * x_{ref} \tag{22}$$

$$b = \frac{p_{ref}}{x_{ref}} * \frac{1}{\epsilon} \text{ with } \epsilon > 0, \tag{23}$$

with p_{ref} and x_{ref} being a reference price and demand, respectively, it holds true that

$$\frac{a}{b} = (1 + \epsilon) * x_{ref}. \tag{24}$$

Consequently, the lower the elasticity in the reference point, ϵ, i.e., the steeper the linear inverse demand function, the lower the optimal quantities when firms optimise their quantities separately. Thus, the less elastic the linear inverse demand function of the composite good, the lower the critical capacity constraint, $\overline{x}_b$ becomes (Conjecture 1). The intuition behind this finding is that the steeper the demand function, i.e. the lower the point elasticity, the lower the equilibrium output. The lower the equilibrium output is the less restrictive is the capacity constraint. Furthermore, the less restrictive the capacity constraint of the integrated firm, the longer the effect of simultaneous optimising (avoiding marginalisation of both divisions).

3. A spatial equilibrium model of the global iron ore and coking coal market

3.1. Steelmaking and the markets for iron ore and coking coal

In general, there are two main routes to produce crude steel, which is an alloy of iron and carbon.[4] One option, also referred to as the "oxygen route", is an integrated steel-making process involving blast furnace (BF) production of pig iron followed by a basic oxygen furnace (BOF). Alternatively, an electric arc furnace (EAF) process may be applied (the so called "electric route"), which mainly uses recycled steel (steel scrap) for steelmaking, and may also use direct reduced iron (DRI) to substitute steel scrap. Roughly 30% of global steel supply is produced using EAFs, with the remainder relying on integrated steel-making.

The main difference between the two production methods is that the basic oxygen steelmaking process is self-sufficient in energy, i.e., the energy is generated during the process by the reaction of oxygen and carbon, with coke being the main source of carbon. This is not the case with EAF steelmaking, as an EAF mainly relies on the use of electricity for melting the steel scrap and DRI. Therefore, no coke is used in electric arc furnaces. Against the background that coke is essentially coking coal without impurities, it is obvious that almost the entire global coking coal supply is used in coke ovens and, therefore, in the basic oxygen steelmaking process. Furthermore, due to its chemical properties and the existence of cheaper alternative coal types (mainly thermal coal and lignite), coking coal is not used in electricity generation. Albeit to a lesser extent, this also holds true for iron ore, with the reason being that the major part of total steel scrap supply is used in EAFs, thereby reducing the need for direct reduced iron. In 2012, pig iron production amounted to 1112 Mt, while direct reduced iron production was 71 Mt, i.e., DRI accounted for 6% of global iron production (WSA, 2013). Consequently, iron ore and coking coal are complementary goods needed to produce pig iron, with both inputs being (almost exclusively) used in this single application.

[4] The interested reader is referred to Figure A.1 in Appendix A for a graphical overview of the two most important steelmaking processes and the required inputs.

Furthermore, both markets, the one for iron ore as well the one for coking coal share two interesting characteristics: First, international trade of both commodities is highly concentrated, as the biggest four exporting companies in the coking coal and iron ore market were responsible for 45% and 67% of total trade volume in 2010, respectively. Second, three global mining companies, namely BHP Billiton, Rio Tinto and Anglo American, are among the top four exporting companies in both markets. Hence, not only are they parallel vertically integrated companies, i.e. they produce both complementary inputs, but, in addition, they may have considerable market power. Given the setting of complementary inputs and market concentration, integrated companies active in both markets may have incentives to maximise their profits by simultaneously choosing their iron ore and coking coal production volumes and not separately, i.e. by division or business unit.

3.2. Model logic and formulation

The partial equilibrium model presented in this section is programmed as a mixed complementary problem (MCP). The model aims at maximising annual profits of the global mining companies producing iron ore and coking coal subject to production constraints and given the various costs along the supply-chain, such as seaborne and inland transport costs. Section 2, albeit in a simplified setting (i.e., non-spatial market, with only one consuming region and homogeneous players) already discusses a firm's profit function under independent ownership and parallel vertical integration. Here, the discussion of the model focuses only on the first-order and the market clearing conditions, thus we do not explicitly write down the respective profit functions. Similar to the model presented in the previous section, we assume that the composite good's price ($\lambda_{d,y}$) in demand region d linearly depends on the composite good's (pig iron) demand (which is equal to pig iron production $pi_{d,y}$). Thus, $\lambda_{d,y} = int_{d,y} - slo_{d,y} * pi_{d,y}$.[5] [6]

The model distinguishes the physical transports of input factor i by mining company c in year y produced in mine m to a demand market d ($tr_{c,i,m,d,y}$) and the sales of a company to a market

[5] Although all sets, parameters and variables used throughout this subsection are explained in the text, the reader is referred to Table B.1 in Appendix B for an overview of the nomenclature.

[6] To keep the formulae as simple as possible, all parameters used in the model description have been adjusted for the factor intensity.

($sa_{c,i,d,y}$). If the firm is optimised simultaneously, it can also sell both composites as a bundle ($sa^b_{c,d,y}$).

Transports $tr_{c,i,m,d,y}$ are constrained by the annual production capacity $cap_{c,i,m,y}$ of mine m. Hence, the amount of transported volumes is subject to the following constraint

$$cap_{c,i,m,y} - \sum_{d \in D} tr_{c,i,m,d,y} \geq 0 \quad \forall c, i, m, y \qquad (\mu_{c,i,m,y}), \tag{25}$$

thereby $\mu_{c,i,m,y}$ represents the value of an additional unit of production capacity at mine m in year y, which may also be interpreted as a scarcity rent of production capacity.

For each input, the sum of transported volumes to a demand market has to equal the sales of each company. If simultaneous optimisation is enabled the parameter sim_c is equal to 1.

$$\sum_{m \in D} tr_{c,i,m,d,y} = sa_{c,i,d,y} + sa^b_{c,d,y} * sim_c \quad \forall c, i, d, y \qquad (v_{c,i,d,y}), \tag{26}$$

thereby $v_{c,i,d,y}$ can be interpreted as the physical value of the transported goods, i.e. the sum of production costs, scarcity rent and transport costs.

A mining company is only willing to produce and transport a good to a market if the sum of production costs, scarcity rent and transport costs is covered by the resulting physical value in the market.

$$\begin{aligned} \frac{\partial \text{Ł}_{\Pi_c}}{\partial tr_{c,i,m,d,y}} = &- v_{c,i,d,y} + pco_{i,m,y} + tco_{i,m,y} \\ &+ \mu_{c,i,m,y} \geq 0 \quad \perp \quad tr_{c,i,m,d,y} \geq 0 \qquad \forall c, i, m, d, y. \end{aligned} \tag{27}$$

Each mining company c maximises its profit by selling volumes to demand region d as long as the price of the input factor ($\rho_{i,d,y}$) exceeds the value of the good $v_{c,i,d,y}$. In case the company is assigned market power (which is indicated by setting the binary parameter $cva_{c,y}$ equal to one), $\rho_{d,i,y}$ must not only exceed physical delivery costs but also the company's mark-up, which depends on the slope of the composite good's demand function ($slo_{d,y}$) and sales volume of the company ($sa_{c,i,d,y}$ and $sa^b_{c,d,y} * sim_c$ in case simultaneous optimisation is possible).

$$\begin{aligned}\frac{\partial \mathrm{L}_{\Pi_c}}{\partial sa_{c,i,d,y}} =& - \rho_{d,i,y} - cva_{c,y} * slo_{d,y} * (sa_{c,i,d,y} + sa^b_{c,d,y} * sim_c) \\ &+ \upsilon_{c,i,d,y} \geq 0 \quad \perp \quad sa_{c,i,d,y} \geq 0 \qquad \forall c, i, d, y.\end{aligned} \tag{28}$$

If an integrated mining company decides to optimise its divisions simultaneously it has to decide additionally about the amount of bundles of complementary input factors it sells to each market. The price of both input factors, i.e. the bundle has to equal the oligopolistic mark-up (see Equation 16) plus the physical value of both inputs.

$$\begin{aligned}\frac{\partial \mathrm{L}_{\Pi_c}}{\partial sa^b_{c,d,y}} =& - \sum_i (\rho_{d,i,y}) - cva_{c,y} * slo_{d,y} * \left(\sum_i (sa_{c,i,d,y}) + sa^b_{c,d,y} * sim_c\right) \\ &+ \sum_i \upsilon_{c,i,d,y} \geq 0 \quad \perp \quad sa^b_{c,d,y} \geq 0 \qquad \forall c, d, y.\end{aligned} \tag{29}$$

Finally, in order to model an oligopoly in complementary goods the model encompases three market clearing conditions:

$$\lambda_{d,y} = int_{d,y} - slo_{d,y} * pi_{d,y} \quad \perp \quad \lambda_{d,y} \quad \text{free} \qquad \forall d, y \tag{30}$$

$$pi_{d,y} = \sum_{c \in C} (sa_{c,i,d,y} + sa^b_{c,d,y} * sim_c) \quad \perp \quad \rho_{i,d,y} \quad \text{free} \qquad \forall i, d, y \tag{31}$$

$$- \lambda_{d,y} + \sum_{i \in I} \rho_{i,d,y} \geq 0 \quad \perp \quad pi_{d,y} \geq 0 \quad \forall d, y. \tag{32}$$

These market clearing conditions determine three things: First, Equation 30 determines the price of pig iron ($\lambda_{d,y}$) using the inverse linear demand function. Second, Equation 31 states that each input's total sales (including bundles of input factors) to demand region d needs to equal total pig iron demand ($pi_{d,y}$). This equation is used to model iron ore and coking coal as complementary goods, with the composite good being produced using a fixed-proportion production technology. Finally, Inequality 32 needs to be incorporated to establish the relationship between input factor prices ($\rho_{i,d,y}$) and pig iron price ($\lambda_{d,y}$). For simplification, we assume that the pig iron price is fully explained by the prices of iron ore and coking coal, i.e. does not include any further marginal costs for the production process. This does not effect the results qualitatively though as the final product's price is of no further importance for our analysis.

3.3. Data and scenario setting

This subsection describes the data of the iron ore and coking coal market that we use in the numerical simulation. The dataset comprises demand, production and transport data of the years 2008 to 2010.

3.3.1. Demand data

Iron ore consumption data in international statistics (e.g., World Steel Association (WSA)) is usually specified in metric tons thereby abstracting from the iron content in the ore (Fe-content). This however complicates our analysis: As we are interested in iron ore consumption as an input in pig iron production, it necessitates information on the amount of pure iron contained in the consumed ore. For example, a country has an annual consumption of 1 million tonnes (Mt) of iron ore. It is supplied by one producer delivering 0.7 Mt of 40% Fe and another delivering 0.3 Mt of 60% Fe. Thus, the country consumes 0.46 Mt of pure iron. A second country also consumes 1 Mt of iron ore, but the material has an iron content of 65% Fe. Hence the country consumes 0.65 Mt of pure iron. Even though both countries consume 1 t of iron ore, the pure iron consumption as an input for pig iron production is nearly 50% higher in the second country.

To cope with this problem, we use annual pig iron production data provided by WSA as a proxy for the actual iron ore consumption, thereby assuming that 1 Mt of pure iron is consumed to produce 1 Mt of pig iron.

Concerning coking coal we do not face this problem as we account for coking coal consumption specified in energy units (IEA, 2012). However, it is necessary to define the factor intensity of coking coal in pig iron production. Comparing coking coal consumption and pig iron production we assume a factor intensity of 70% which means that 0.7 Mt of coking coal are needed to produce 1 Mt of pig iron.

We assume that in the simulation model both iron ore and coking coal are exclusively used for pig iron production. In reality, 6% of global annual iron ore production serves as input for so-called direct reduced iron (DRI). Concerning coking coal, IEA statistics suggest that some minor quantities (4% globally) of coking coal are used for power generation as well. We correct our data for this in the following to limit complexity of our analysis. For the same reason, we abstract from stocking of iron ore or coking coal that can be observed in both markets.

As stated in chapter 3, linear price-demand functions for pig iron are required in order to simulate different market settings. To derive those country specific demand functions we stick to an approach which has been widely used in literature on market models programmed as a mixed complementary problem (MCP): Using a reference price, a reference volume and an elasticity yields slope and intercept of the demand function. We use the annual pig iron production as reference volume. The reference price is however more difficult to obtain since we are not interested in the real pig iron price (containing price elements such as labour costs) but only the part of the price that can be explained by those input factors being in the scope of our analysis, i.e. the prices of iron ore and coking coal. The reference price is therefore calculated as follows

$$p_{pi} = p_i + p_c. \tag{33}$$

The annual average prices of iron ore and coking coal are derived based on information from BGR (2008-2011) and BREE (2011).

3.3.2. Production data

We include detailed iron ore production data containing mine-by-mine production costs and region specific iron contents (World Mine Cost Data Exchange, 2013). Concerning coking coal we integrate the dataset of Trüby (2013) comprising mine-by-mine production costs as well. The production costs have to be interpreted as free on board costs i.e. inland transport costs are already taken into account. Additionally, we analyse historic iron ore and coking coal production data of the most important export companies such as Vale, Rio Tinto, BHP Billiton (BHPB), Anglo American/Kumba, XStrata or FMG using their annually published production reports.

Using those data sources in addition to annual country specific production and export volumes (iron ore: WSA (2010, 2011, 2012), coking coal: IEA (2012)), we obtain a detailed and nearly complete dataset of both factor market's supply side.

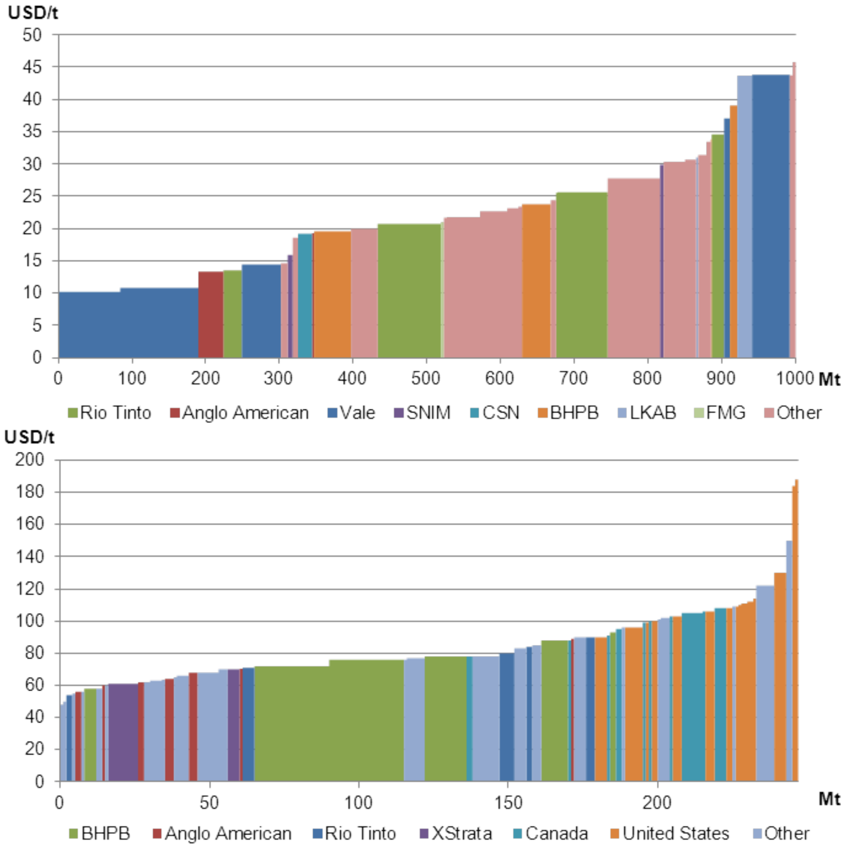

Figure 4: Iron ore and coking coal FOB cost curves of major exporters in 2008

However, for two major producing countries it is difficult to access detailed mine sharp production data in both markets: China and India. For China, World Steel Dynamics (2011) provides us with cost and capacity information on iron ore production differentiating between several cost levels. Concerning Chinese coking coal production and both inputs in India, we use the annual iron ore production from WSA respectively the annual coking coal production from IEA (2012), however not differentiating between different mines. This simplification does not severely affect our analysis as both in China and in India there is no dominant iron ore or coking coal producer that has a significant influence on global trade. Therefore, we assume an atomistic supply side in those two countries, i.e. iron ore and coking coal producers from both countries are modeled as competitive players.

Players modeled as Cournot players are Vale, RioTinto, BHPB, FMG, Anglo American (Kumba), CSN, LKAB and SNIM in the iron ore market and Rio Tinto, BHPB, Anglo American and XStrata in the coking coal market. In line with Trüby (2013), we model US coking coal exporters as one Cournot player (US_CC), since the main export ports and the inland transport rails are controlled by one player and market power is assumed to be exerted via the infrastructure. Other smaller and mostly domestic producers are assumed to market their production volumes as competitive players.

Figure 4 shows the global FOB supply cost curves of major iron ore and coking coal exporters in 2008. Note that this figure does not reflect the seaborne traded iron ore volumes exactly since exporters also partly supply their domestic markets as well. We observe that regarding production costs the big three iron ore exporters Vale, Rio Tinto and BHP Billiton are for most part in the lower half of the global FOB cost curve.

3.3.3. Transport data

The IOCC dataset comprises distances between major export and import ports using a port distance calculator. Additionally, the dataset contains freight rates of 2008 to 2010 of bulk carrier transports on numerous shipping routes. Using freight rates and transport distances we calculate a proxy for the seaborne transport costs. For most of the inland transport routes, costs are already accounted for since the cost data are free on board (FOB), i.e., the costs comprise production, inland transport and port handling costs. The only exception is inland transports from Russia to Europe respectively China where rail freight rates are used.

To limit model complexity, we do not explicitly account for capacity limitations of neither port nor rail infrastructure nor ship capacities. We implicitly assume that scarce bulk carrier capacities are already represented by the freight rates. Capacity limitations of export port or rail infrastructure both are subsumed under the production capacity of a production region. For example, if a production region has a capacity of 100 and the according port only has a capacity of 80, the production capacity we use in our model is 80.

4. Results of the applied analysis

4.1. The profitability of parallel vertical integration in the iron ore and coking coal market

We apply our computational model to investigate whether or not firms benefit from behaving parallel vertically integrated. Therefore, in a first step, we simulate the iron ore and coking coal market for the years 2008 to 2010 to derive the profitability of the integrated companies Anglo American, Rio Tinto and BHP Billiton. Since the strategy choice of the competitors might influence the profitability of the own strategy, we model a simple static simultaneous game with two stages. In the first stage, each integrated company chooses between two strategies: "optimising simultaneously (SIM)" and "optimising separately (SEP)". In the second stage, all companies in the iron ore and coking coal market (also companies active in only one of the markets) set the production quantities, thereby knowing each of the integrated companies' strategy choices, SIM or SEP. Thus, in total we simulate 8 model runs and use each company's total profit margin as payoff function.[7]

The question arises if the proposed two-stage game is a realistic representation of the market. Is an integrated company able to credibly commit optimising both divisions separately and can this be observed by the other players? The commitment for separate optimisation could be realised by incentive contracts for the division managers, e.g. by remuneration depending on profitability of the division. Although these contracts are unlikely to be seen by the other players, separate optimisation could be observable by founding a subsidiary company for e.g. the iron ore business. Ideally, the holding would sell minor shares of the subsidiary in order to further incentivise that each division is optimizing itself separately. Although in reality, iron ore and coking coal businesses of integrated companies are rather subdivisions[8] than subsidiaries, the strategy SEP could per se be committed to in a credible and observable way.

Figure 5 illustrates the profitability of choosing SIM over SEP for each of the three integrated companies given the other companies' strategy choices and the assumed demand elasticity (nota-

[7] Since we have no data about fixed costs of iron and coking coal mining, we focus on the profit margin, i.e. price minus marginal costs times quantity sold. This is sufficient for our analysis since we only compare differences of profit margins whereas fixed costs only change the level of the total profits.

[8] Interestingly, for both Rio Tinto and BHP Billiton, the head offices of the iron ore divisions are situated in Perth, the coal divisions in Brisbane and the holdings in Melbourne.

tion: b = BHP Billiton, r = Rio Tinto, a = Anglo American, 1 = SIM, 0 = SEP). The profitability is derived as the difference in profit margins between option SIM and option SEP. These results seem to confirm Conjecture 3 from 2.2: The more inelastic the demand is, the higher is the additional benefit of choosing SIM over SEP. With an increasing demand elasticity the additional benefit of SIM converges to zero.[9]

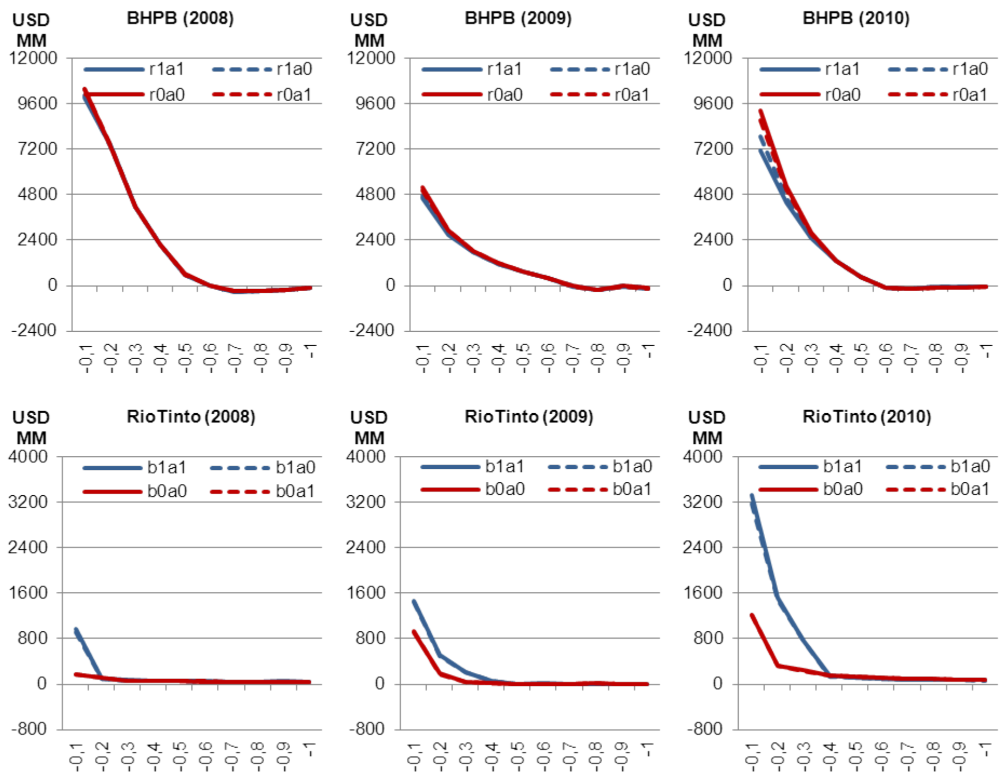

Figure 5: Difference in profits of optimizing simultaneously (SIM) or separately (SEP) depending on the other integrated companies' strategy.

As stated in 2.2, capacity constraints of at least one of the complementary goods seem to be one explanation for the decreasing profitability of strategy SIM. For BHP Billiton, for example, the iron ore capacity is binding in all three years as soon as the demand elasticity (in absolute terms) is higher than 0.5. Rio Tinto's coking coal capacity is binding in all of the scenarios and the iron ore capacity becomes binding for elasticities of 0.3 and 0.4 and higher. This might be an

9 For BHP Billiton, we observe slightly negative values for the years 2008 and 2009. This phenomenon can be explained by numerical reasons during the solution process of the model. The loss when choosing strategy SIM seems negligible since it is at highest 1% of the profit margin.

explanation why the additional benefit of strategy SIM is generally higher for BHP Billiton than for Rio Tinto.

4.2. A comparison of three market settings

So far, the model results revealed that SIM is a beneficial strategy for integrated companies if the demand is rather inelastic or, in other words, if the production capacity of both complementary goods is not scarce. However, the outcomes of SIM and SEP are equal when higher demand elasticities are assumed. In the following, to find evidence whether or not integrated players optimise their iron ore and coking coal divisions simultaneously, we investigate which of the strategy choices and which demand elasticities best represent historical market outcomes. Therefore we compare model results and historical market outcomes, i.e., prices, trade flows and production volumes.

In total, we focus on three market settings in this section: First, we investigate whether non-competitive behaviour is observed in both the iron ore and the coking coal market. Hence, we run a scenario in which all players in the market behave in a perfectly competitive manner ("Perfect competition"), i.e., act as price takers. Second, we run another two model simulations each assuming Cournot behaviour in both markets. One in which Anglo American, BHP Billiton and Rio Tinto behave as parallel vertically integrated firms ("SIM") and another one in which each of those firms' iron ore and coking coal business units optimise their profits separately ("SEP"). By comparing model outcomes to actual price, production and trade data for the time period from 2008 to 2010, we aim at identifying the setting that has the better fit with the realised values. To compare trade flows we use three statistical tests discussed in Appendix D.[10]

Starting with the analysis of the "Perfect competition" setting, we find that the test statistics of the F-test allow us to reject the null hypothesis ($\beta_0 = 0$ and $\beta_1 = 1$) on a 99.9% level for both goods in all years and elasticities (Table 2). Interestingly, whereas this result is confirmed by higher Theil's inequality coefficients and lower Spearman rank correlation coefficients in the case of iron ore in all years, this is not the case with coking coal trade flows in 2008 (Figure 6).

[10] The interested reader is referred to Appendix E for a series of tables displaying trade flows for both commodities at a demand elasticities of -0.5 as well as actual trade flows in the respective years.

However, considering prices and production in the perfect competition setting (PC) in addition to the trade flows, we conclude that the two market settings, in which players behave in a non-competitive manner, outperform the perfect competition setting. The model when run with all players acting as price takers cannot reproduce iron ore prices for most part of the elasticities that were investigated (Figure 7). In addition, total production of both commodities is too high in this market setting and, more importantly, the model cannot capture production behavior of the largest company in each market (Figure 8), i.e., Vale in the case of iron ore and BHP Billiton in the case of coking coal: For almost each assumed demand elasticity, these producers produce up to full capacity.

Table 2: P-values of the F-tests ($\beta_0 = 0$ and $\beta_1 = 1$) for a wide range of elasticities

Coking	Perfect competition			Separate			Simultaneous		
coal	2008	2009	2010	2008	2009	2010	2008	2009	2010
e = -0.1	0.01**	0.00***	0.00***	0.08*	0.04**	0.03**	0.64	0.14	0.49
e = -0.2	0.01***	0.00***	0.00***	0.22	0.06*	0.04**	0.39	0.08*	0.44
e = -0.3	0.01***	0.00***	0.00***	0.46	0.12	0.14	0.37	0.11	0.33
e = -0.4	0.01***	0.00***	0.00***	0.64	0.26	0.50	0.36	0.14	0.36
e = -0.5	0.01***	0.00***	0.00***	0.71	0.54	0.93	0.32	0.14	0.31
e = -0.6	0.01***	0.00***	0.00***	0.63	0.92	0.59	0.27	0.13	0.20
e = -0.7	0.01***	0.00***	0.00***	0.41	0.92	0.20	0.19	0.11	0.10*
e = -0.8	0.01***	0.00***	0.00***	0.26	0.56	0.08*	0.11	0.09*	0.08*
e = -0.9	0.00***	0.00***	0.00***	0.13	0.38	0.07*	0.08*	0.05*	0.07*
e = -1.0	0.00***	0.00***	0.00***	0.10*	0.12	0.07*	0.06*	0.04**	0.06*
Iron	Perfect competition			Separate			Simultaneous		
ore	2008	2009	2010	2008	2009	2010	2008	2009	2010
e = -0.1	0.00***	0.00***	0.00***	0.85	0.15	0.32	0.87	0.41	0.55
e = -0.2	0.00***	0.00***	0.00***	0.88	0.62	0.72	0.91	0.89	0.95
e = -0.3	0.00***	0.00***	0.00***	0.66	0.87	0.95	0.74	0.79	0.73
e = -0.4	0.00***	0.00***	0.00***	0.37	0.62	0.79	0.59	0.25	0.41
e = -0.5	0.00***	0.00***	0.00***	0.18	0.13	0.44	0.42	0.03**	0.19
e = -0.6	0.00***	0.00***	0.00***	0.09*	0.01**	0.19	0.27	0.00***	0.09*
e = -0.7	0.00***	0.00***	0.00***	0.04**	0.00***	0.09*	0.17	0.00***	0.05*
e = -0.8	0.00***	0.00***	0.00***	0.02**	0.00***	0.05**	0.08*	0.00***	0.03**
e = -0.9	0.00***	0.00***	0.00***	0.01***	0.00***	0.05**	0.06*	0.00***	0.03**
e = -1.0	0.00***	0.00***	0.00***	0.01***	0.00***	0.01**	0.06*	0.00***	0.01**

Significance levels: 0.01 '***' 0.05 '**' 0.1 '*'

Concerning the comparison of the SIM and the SEP setting, the picture is more ambiguous. Starting out by looking at the results of the hypothesis tests for iron ore trade flows, one may be

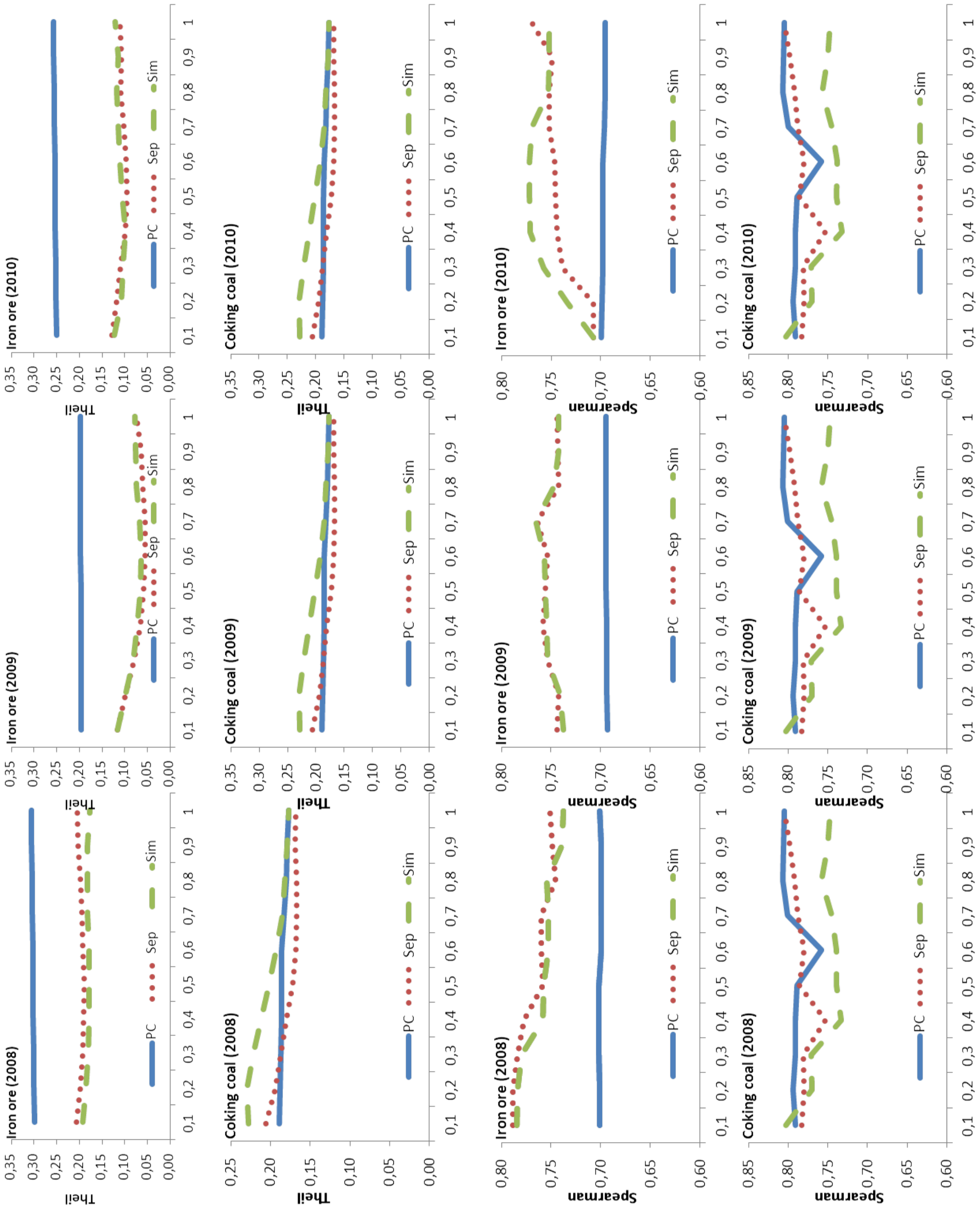

Figure 6: Theil's inequality coefficient and Spearman rank correlation coefficient contingent on the demand elasticity

drawn to the conclusion that both of the two Cournot settings are able to reproduce actual trade flows, as for a large part of the range of elasticities we investigated the hypothesis tests cannot reject the null hypothesis. Contrasting the findings of the linear hypothesis test with Theil's inequality coefficient and Spearman's *rho*, we see from Figure 6 that both non-competitive settings perform similarly well in the case of iron ore. For coking coal, the SEP setting performs better than the SIM setting as Theil's inequality coefficient is lower and Spearman's *rho* is higher than in the SEP setting .

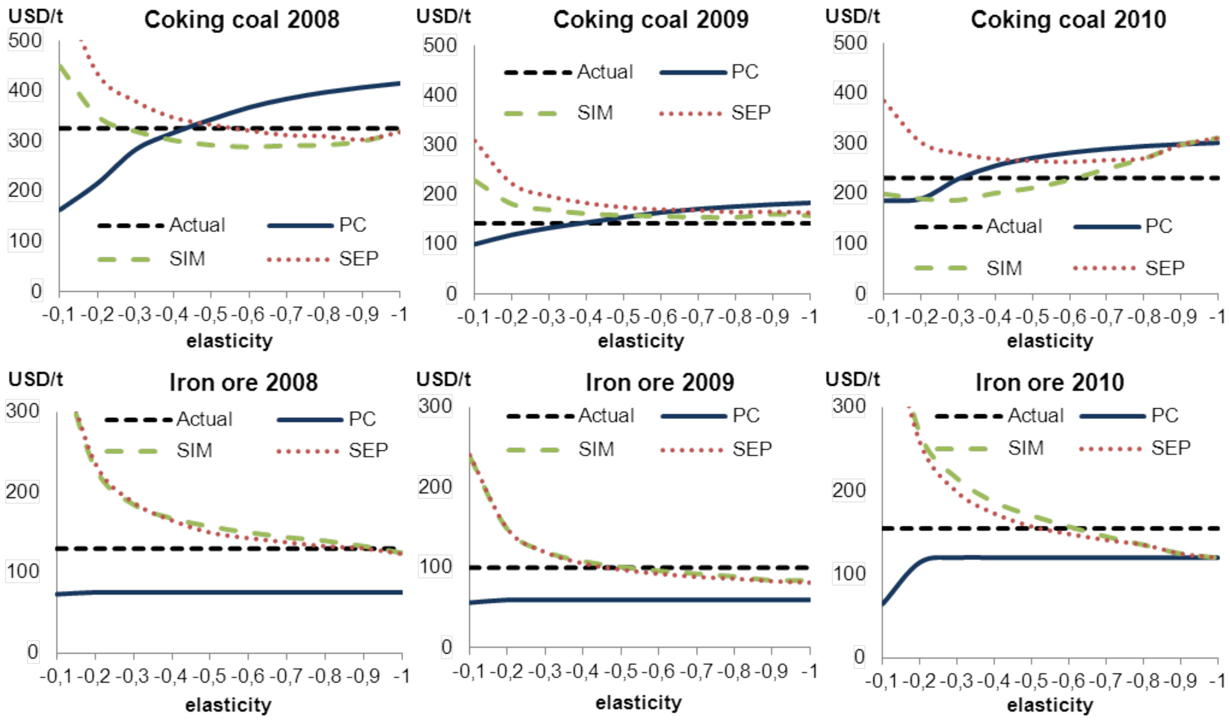

Figure 7: Iron ore and coking coal prices contingent on the demand elasticity

Concerning prices we observe that the SIM setting generates lower coking coal prices and higher iron ore prices than the SEP setting, although the simulated iron ore prices are very similar with the difference never exceeding 8%. Iron ore prices match the actual market outcome for the years 2009 and 2010 for an assumed demand elasticity of -0.5 to -0.6. In this range of elasticities for the year 2008, the simulation results overestimate the actual iron ore prices by 20 USD/t (SEP) and 27 USD/t (SIM). Concerning coking coal the SEP setting fits the actual coking coal price of 2008 for an assumed demand elasticity of -0.5 to -0.6 whereas the SIM setting underestimates the price by 35 USD/t. In contrast, for 2009, the SIM setting is closer to the actual coking coal price than SEP in the whole range of simulated elasticities. For a demand elasticity of -0.5 to -0.6 the differences to the actual values are 15 USD/t and 30 USD/t, respectively. For the year 2010 and a demand elasticity of -0.6, the SIM setting seems more appropriate to represent the coking coal price.

Finally, we take another look at the company's production output depicted in Figure 8. Whereas the iron ore production is similar in both scenarios (see the example of Vale in Figure 8), the coking coal production volumes differ significantly in the case of BHP Billiton and the US coking coal player. The SIM case overestimates the actual production volumes of BHP in the whole range of elasticities in all years. In the SEP case the BHP production volume is matched at elasticities of -0.5 to -0.7 between 2008 and 2010. The US coking coal production in the SIM case is always lower than in the SEP case. For lower elasticities the SEP case is closer to the actual production whereas the production volumes converge for higher elasticities in the years 2008 and 2010.

Summing up, we found no evidence supporting the idea that players in the two commodity markets behave in a perfectly competitive manner. Consequently, the two non-competitive market settings resulted in market outcomes that match actual outcomes better than in the perfect competition case. Regarding the comparison of the case of SEP and SIM optimisation of the business units' profits, we did not find overwhelming evidence to dismiss one of the two settings. But, the results of the statistical tests and the comparison of production and price data draw a more consistent picture in the SEP than in the SIM setting, with the model performing best for elasticities of -0.5 and -0.6.

4.3. Strategic implications

The comparison of actual market outcomes and model results provide an indication that the SEP setting best represents the market outcome. However, since the analysis did not allow to unambiguously opt for one setting this subsection aims at delivering an economic argument why the three merged companies might indeed have chosen strategy SEP over SIM in reality.

If a firm decides to optimise both the coking coal and the iron ore division simultaneously (i.e. choosing strategy SIM), a sophisticated organisational structure is required such that the

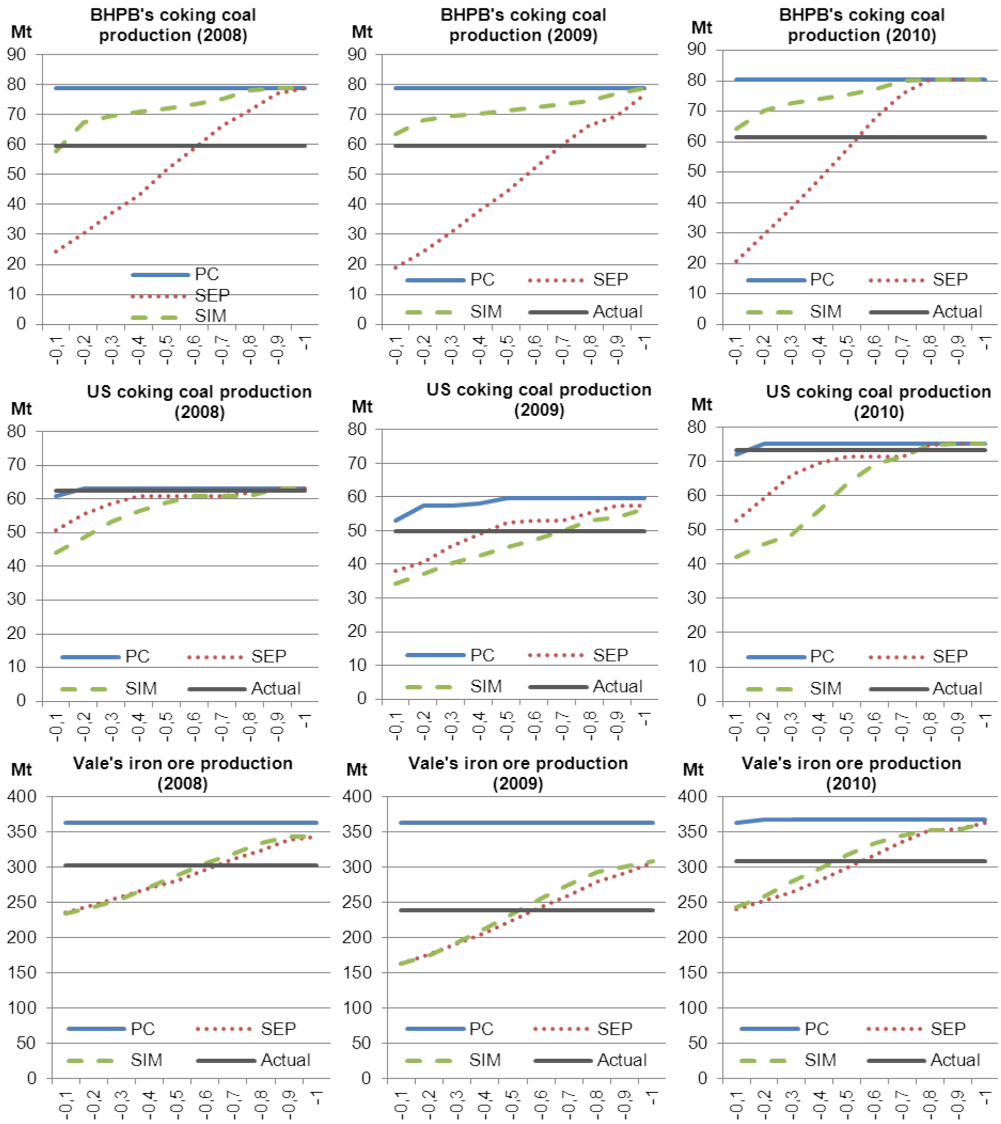

Figure 8: Production of Vale, BHP Billiton and US coking coal producers depending on the demand elasticity and the market setting

economic agents within the firm are incentivised to act in a way which in fact leads to a global optimum. Both divisions have specialized knowledge regarding their specific markets, they possess a high technical know how, they know their production costs and capacities and have an idea about their own market position compared to their competitors. However, to make both divisions act according to strategy SIM, it is required that both divisions coordinate themselves to sell the optimal combination of coking coal and iron ore to a demand market. And even more challenging, the division managements have to be incentivised to act as such. Höffler and Sliwka (2012) discuss that symmetric incentives based on the units' performance provide incentives for haggling within the organisation whereas symmetric incentives based on the overall profit would lead to free-rider behaviour because of reduced individual responsibility for the overall performance.The authors state that these inefficiencies become stronger with increasing interdependencies between units. They find that asymmetric incentive structures which make one unit dominant in the organisation could reduce these inefficiencies: The dominant unit should have unit based incentives whereas the other unit should have incentives based on the overall profit.

Although asymmetric incentive structures reduce organisational inefficiencies, simultaneous optimisation of the divisions nevertheless incurs additional transactional and organisational costs. Coming back to the finding from Section 4.1 an integrated company will only choose SIM over SEP, if the additional profit from SIM is sufficiently high to overcompensate the additional transactional and organisational costs incurred by strategy SIM. As seen before, this is only the case if the production capacity of both goods is sufficiently high to benefit from SIM by increasing the output. The lower the demand elasticity becomes, the less restrictive the capacity constraint. In the real world application, we have seen that BHP Billiton is the leading company in the coking coal market but faces a binding capacity constraint in the iron ore market the higher the assumed demand elasticity is. Therefore, the extra benefit of SIM versus SEP tends to zero for higher elasticities whereas it can become significant for lower demand elasticities. The simulation however reproduced more consistent market results when simulating elasticites of -0.5 to -0.6 where the benefit of simultaneous optimisation was converging to zero.

5. Conclusions

In this paper, we have assessed the profitability of parallel vertical integration in quantity-setting oligopolies of complementary goods from a theoretical perspective and in a real world application. The markets for iron ore and coking coal provide a good example for this setting: Both goods are complementary inputs for steel production, they have little alternative use, they exhibit a high supply side concentration and some of the biggest producers are active on both markets.

We first assessed parallel vertical integration of two firms in a theoretical model of two homogeneous Cournot duopolies of complementary goods and linear demand of the final good. We considered two cases: one with unlimited capacities and one with a binding capacity constraint on one of the merging firms' production. The merger is always profitable if capacities are unlimited. In contrast the profits of the remaining, i.e. not mergerd, firms' decrease. However, we proved three conjectures for the case of one of the merging firms having a binding capacity constraint. There exists a critical capacity constraint (i) below which the merging firms are indifferent to the merger, (ii) above which the merger is always beneficial and (iii) the lower the demand elasticity the smaller this critical capacity constraint becomes.

Next, we investigated whether these findings hold for the real world application as well. The markets for iron ore and coking coal are however more complex than the theoretical model as there are more than two suppliers in each market, there are more than one parallel vertically integrated firms, production costs are heterogeneous, both markets are spatial markets and most of the producers face a binding capacity constraint. Therefore, we developed a numerical spatial multi-input equilibrium model of both markets based on a unique data set. Assessing the profitability of the integrated companies, the results from the theoretical model were confirmed in the simulation. The coking coal market leader BHP Billiton generates additional profits from simultaneous optimisation for low elasticities because its iron ore capacity is not binding. With increasing demand elasticity the benefits of simultaneous optimisation tend to zero. Last, we compared the model results of one simulation assuming separate optimisation and another one assuming simultaneous optimisation to actual price, trade flow and production data for the years 2008 to 2010. Although no scenario dominates the other one, the scenario assuming separate optimisation fitted the actual market outcomes slightly better.

Apart from the argumentation within this analysis, there might be other economic reasons for separate optimisation of both business units that were not the main focus of this paper and might be interesting for further research. For example, the simultaneous optimisation of two business units could create inefficiently high organisational costs. Furthermore, it might therefore be challenging to create incentives for both divisions not to optimise the division but the whole company. Since this analysis focused on a comparison of historic and model based market outcomes, it may be insightful to further assess the strategic investment of companies in a prospective analysis. The decision whether to grow in one or the other complementary factor market, thereby altering the own strategic position or the one of the competitor, may be another interesting sequel to this paper.

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Appendix A. Steelmaking

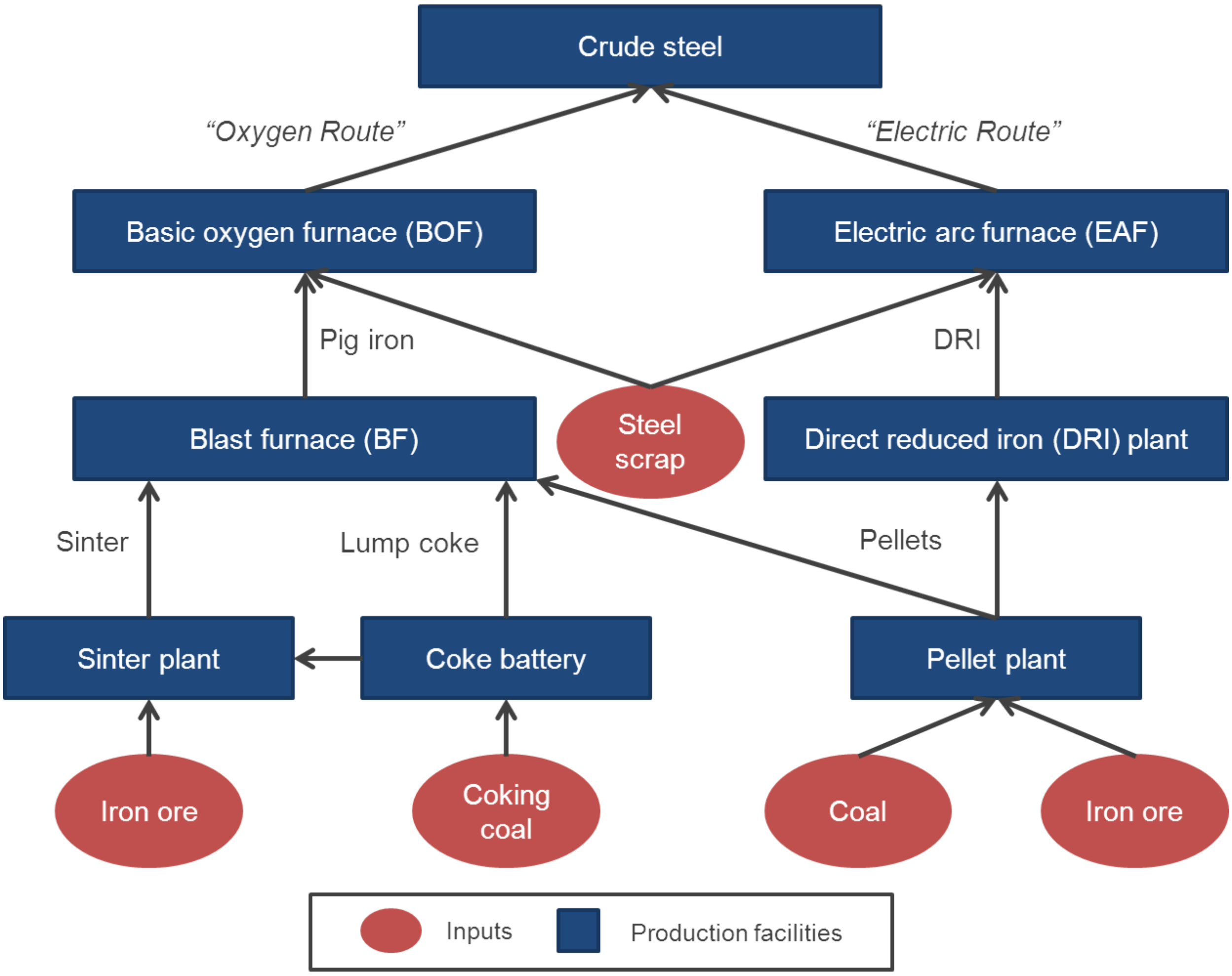

Figure A.1: Overview of crude steel production

Appendix B. Model overview

Table B.1: Model sets, variables and parameters

Sets	
$n \in N$	all model nodes
$y \in Y$	years
$i \in I$	inputs
$c \in C$	mining companies
$m \in M \in N$	mines
$d \in D \in N$	importing regions
Variables	
$pi_{d,y}$	pig iron demand / production in import region d
$tr_{c,i,m,d,y}$	transport of input i from mine m to import region d
$sa_{c,i,d,y}$	sales of input i to import region d
$sa^b_{c,d,y}$	sales of a bundle of inputs to import region d
$\lambda_{d,y}$	price of pig iron in import region d
$\rho_{i,d,y}$	price of input i in import region d
$v_{c,i,d,y}$	physical value of input i for company c to produce and to transport in import region d
$\mu_{c,i,m,y}$	marginal benefit of an additional unit of production capacity of input i at mine n
Parameter	
$cap_{c,i,m,y}$	annual production capacity of input i at mine m
$fin_{d,i,y}$	factor intensity of input i in crude steel production in import region d
$pco_{i,m,y}$	free-on-board costs of input i produced in mine m
$tco_{i,m,d,y}$	seaborne transport costs of input i (produced in mine m) to import region d
$cva_{c,y}$	company c's conjectural variation
$slo_{d,y}$	slope of linear pig iron demand function
$int_{d,y}$	intercept of linear pig iron demand function
sim_c	binary parameter indicating whether integrated company c optimises simultaneously

Appendix C. Oligopolistic market with a binding capacity constraint on one firm's output

We are interested in a setting shown in Figure 1, i.e., with four independent firms. However, this time we introduce a binding capacity constraint on one of the firms output, e.g., $\mathring{x}_i^1$. The first-order conditions of the firms with no capacity limit are equivalent to Equation 5. Using the first-order conditions and inserting them in the price formulas yields:

$$\begin{aligned} p_c &= a - bx_c^1 - bx_c^2 - p_i = a - p_c - p_c - p_i \\ \Leftrightarrow p_c &= \frac{a - p_i}{3} \end{aligned} \tag{C.1}$$

and

$$\begin{aligned} p_i &= a - bx_i^1 - b\mathring{x}_i^1 - p_c = a - p_i - b\mathring{x}_i^1 - p_c \\ \Leftrightarrow p_c &= \frac{a - b\mathring{x}_i^1 - p_c}{2}. \end{aligned} \tag{C.2}$$

Using Equations C.1 and C.2 yields:

$$\begin{aligned} p_i &= \frac{3a - 3b\mathring{x}_i^1 - a + p_i}{6} \\ \Leftrightarrow p_i &= \frac{2a - 3b\mathring{x}_i^1}{5} \end{aligned} \tag{C.3}$$

and

$$p_c = \frac{a}{3} - \frac{2a - 3b\mathring{x}_i^1}{15} = \frac{a + b\mathring{x}_i^1}{5} \tag{C.4}$$

as well as

$$\begin{aligned} bx_c^n &= \frac{a + b\mathring{x}_i^1}{5} \\ \Leftrightarrow x_c^n &= \frac{a}{5b} + \frac{\mathring{x}_i^1}{5}. \end{aligned} \tag{C.5}$$

This allows us to derive the profit of two independent firms (i_1 and c_1), of which one has a binding capacity constraint, contingent on $\mathring{x}_i^1$:

$$\begin{aligned}
\pi^{i_1+c_1} &= \mathring{x}_i^1 \left(\frac{2a - 3b\mathring{x}_i^1}{5} \right) + \left(\frac{a}{5b} + \frac{\mathring{x}_i^1}{5} \right) \left(\frac{a + b\mathring{x}_i^1}{5} \right) \\
&= \frac{2a\mathring{x}_i^1 - 3b\left(\mathring{x}_i^1\right)^2}{5} + \frac{a^2 + ab\mathring{x}_i^1}{25b} + \frac{a\mathring{x}_i^1 + b\left(\mathring{x}_i^1\right)^2}{25} \\
&= \frac{10ab\mathring{x}_i^1 + ab\mathring{x}_i^1 - 15b^2\left(\mathring{x}_i^1\right)^2 + b^2\left(\mathring{x}_i^1\right)^2 + a^2 + ab\mathring{x}_i^1}{25b} \\
&= \frac{a^2 + 12ab\mathring{x}_i^1 - 14b^2\left(\mathring{x}_i^1\right)^2}{25b}.
\end{aligned} \tag{C.6}$$

Appendix D. Statistical measures

In order to assess the accuracy of our model, we compare market outcomes, such as production, prices and trade flows, to our model results. In comparing trade flows, we follow, for example, Kolstad and Abbey (1984), Bushnell et al. (2008) and more recently Trüby (2013) by applying three different statistical measures: a linear hypothesis test, the Spearman rank correlation coefficient and Theil's inequality coefficient. In the following, we briefly discuss the setup as well as some of the potential weakness of each of the three tests.

Starting with the linear hypothesis test, the intuition behind the test is that in case actual and model trade flows had a perfect fit the dots in a scatter plot of the two data sets would be a aligned along a line starting at zero and having a slope equal to one. Therefore, we test model accuracy by regressing actual trade flows A_t on the trade flows of our model M_t, with t representing the trade flow between exporting country $e \in E$ and importing region $d \in D$, as data on trade flows is available only on a country level (see Subsection 3.3.3). Using ordinary least squares (OLS), we estimate the following linear equation:

$$A_t = \beta_0 + \beta_1 * M_t + \epsilon_t. \tag{D.1}$$

Modelled trade flows have a good fit with actual data if the joint null hypothesis of $\beta_0 = 0$ and $\beta_1 = 1$ cannot be rejected on typical significance levels. One of the reasons why this test is applied in various studies is that it allows hypothesis testing, while the other two tests used in this paper are distribution-free and thus do not allow such testing. However, there is a drawback to this test as well, since the results of the test are very sensitive to how good the model is able to simulate outliers. Therefore, from our point of view rejecting the null hypothesis is not sufficient to dismiss the model as not being accurate, but instead model accuracy regarding the trade flows is judged based on the overall picture provided by the three tests.

The second test we employ is the Spearman's rank correlation coefficient, which, as already indicated by its name, can be used to compare the rank by volume of the trade flow t in reality to the rank in modelled trade flows. Spearman's rank correlation coefficient, also referred to as Spearman's rho, is defined as follows:

$$rho = 1 - \sum_{t}^{T} d_t^2/(n^3 - n) \tag{D.2}$$

with $d_{i,j}$ being the difference in the ranks of the modelled and the actual trade flows and T being the total number of trade flows. Since Spearman's rho is not based on a distribution hypothesis testing is not applicable, but instead one looks for a large value of rho. However, Spearman's rank correlation coefficient does not tell you anything about how well the predicted trade flows compare volumewise to the actual trade flow volumes, since it could be equal to one despite total trade volume being ten times higher in reality as long as the market shares of the trade flows match.

Finally, we apply the normed-version of Theil's inequality coefficient U, which lies between 0 and 1, to analyse the differences between actual and modelled trade flows. A U of 0 indicates that modelled trade flows perfectly match actual trade flow, while a large U hints at a large difference between the two data sets. Theil's inequality coefficient is defined as:

$$U = \frac{\sqrt{\sum_t^T (M_t - A_t)}}{\sqrt{\sum_t^T M_t^2} + \sqrt{\sum_t^T A_t^2}} \tag{D.3}$$

Appendix E. Trade flows

Table E.1: Realised values: Iron ore and coking coal trade flows in million tonnes

Iron ore (2008)

Importers / Exporters	European Union	Other Europe	CIS	NAFTA	C. & S. America	Africa and ME	Asia	Oceania	**Total**
European Union		1.3	27.8	14.1	78.2	17.9	0.9	5.9	**146.1**
Other Europe	1.7		2.6	0.3	4.2	0.2	0.9	0	**9.9**
CIS	0	0		0.1	0.2	0	0	0	**0.3**
NAFTA	0.1	0	0		6.8	0	0	0	**6.9**
C. & S. America	0	0	0	1.5		0.1	0	0	**1.6**
Africa and ME	6.3	0	0	1.1	2.5		0.2	0	**10.1**
China	0	0	15.3	6.5	119.3	11.3	98.1	183.5	**434.0**
Japan	0	0	0	1.3	38.4	8.1	16.2	76.4	**140.4**
Other Asia	0	0	0	0.8	29.3	0.5	3.6	43.9	**78.1**
Oceania	0	0	0	0	0.4	0	1.7		**2.1**
Total	**8.1**	**1.3**	**45.7**	**25.7**	**279.3**	**38.1**	**121.6**	**309.7**	**829.5**

Coking coal (2008)

Importers / Exporters	**Australia**	**Canada**	**Russia**	**United States**	**Total**
Europe and Mediterranean	27	7	4.1	24.4	**62.5**
Japan	50.2	8.6	2	1.3	**62.1**
Korea	8.4	5.1	0.4	1	**14.9**
China	1.5	0.5	0.2	0	**2.2**
India	24.2	0	0	1.4	**25.6**
Other Asia	6.4	1.1	0	0.1	**7.6**
Brazil	3.9	1.4	0	5.5	**10.8**
Other	15.3	1.4	0.8	1.7	**19.2**
Total	**136.9**	**25.1**	**7.5**	**35.4**	**204.9**

Iron ore (2009)

Importers / Exporters	European Union	Other Europe	CIS	NAFTA	C. & S. America	Africa and ME	Asia	Oceania	**Total**
European Union		1	18	14.7	36.6	8.3	0.3	0.7	**79.6**
Other Europe	1.4		3.1	0.2	2.2	0	0	0	**6.9**
CIS	0	0		0	0	0	0	0	**0.0**
NAFTA	0.1	0	0.1		1.4	0.1	0	0	**1.7**
C. & S. America	0	0	0	1.2		0	0	0	**1.2**
Africa and ME	3.9	0	0	1.8	2.4		0.1	0	**8.2**
China	1.3	0	28.6	9.3	181.8	30.4	88	278.9	**618.3**
Japan	0	0	0.1	0.6	27.1	6.3	8.7	62.6	**105.4**
Other Asia	0	0	0.3	2.5	18.5	6.5	2.6	39.2	**69.6**
Oceania	0	0	0	0.3	0.6	0	0.1		**1.0**
Total	**6.7**	**1.0**	**50.2**	**30.6**	**270.6**	**51.6**	**99.8**	**381.4**	**891.9**

Coking coal (2009)

Importers / Exporters	Australia	Canada	Russia	United States	**Total**
Europe and Mediterranean	15.7	3.5	3.7	18.4	**41.3**
Japan	42.1	6.7	1.3	0.6	**50.7**
Korea	12.8	4.4	0.5	1.6	**19.3**
China	14.8	3.7	1.1	0.9	**20.5**
India	24	0	0	1.9	**25.9**
Other Asia	2.6	0.8	0.1	0.1	**3.6**
Brazil	4.1	0.9	0	6.7	**11.7**
Other	9.2	0.6	0	1.5	**11.3**
Total	**125.3**	**20.6**	**6.7**	**31.7**	**184.3**

Iron ore (2010)

Importers / Exporters	European Union	Other Europe	CIS	NAFTA	C. & S. America	Africa and ME	Asia	Oceania	**Total**
European Union		0.8	34.1	15.6	59.3	14.9	0.6	15.9	**141.2**
Other Europe	1.7		2.9	0.4	3.3	0	0	0	**8.3**
CIS	0	0		0	0	0	0	0	**0.0**
NAFTA	0.1	0	0.2		7.9	0	0	0	**8.2**
C. & S. America	0	0	0	1.9		0	0	0	**1.9**
Africa and ME	5	0	0	1.6	4.5		0	0	**11.1**
China	1.5	0	25.9	10.7	149.4	33.5	105.3	276.1	**602.4**
Japan	0	0	0.2	0.9	41	6.1	4.8	81.4	**134.4**
Other Asia	0	0	0.2	2.5	47.8	2.9	1.5	54.9	**109.8**
Oceania	0	0	0	0.2	1	0	0		**1.2**
Total	**8.3**	**0.8**	**63.5**	**33.8**	**314.2**	**57.4**	**112.2**	**428.3**	**1018.5**

Coking coal (2010)

Importers / Exporters	Australia	Canada	Russia	United States	**Total**
Europe and Mediterranean	20.7	4.8	4.3	27.7	**57.5**
Japan	45.8	8.7	2.1	2.7	**59.3**
Korea	17.4	5.3	1.3	2.7	**26.7**
China	21.9	4.3	2.5	3.8	**32.5**
India	32.3	0	0	2.3	**34.6**
Other Asia	7.4	0.6	0.1	0.2	**8.3**
Brazil	4.2	1.6	0.1	7.1	**13.0**
Other	5	0.7	0.1	1.2	**7.0**
Total	**154.7**	**26.0**	**10.5**	**47.7**	**238.9**

Table E.2: Perfect competition: Iron ore and coking coal trade flows in million tonnes (demand elasticity of -0.5)

Iron ore (2008)

Importers / Exporters	European Union	Other Europe	CIS	NAFTA	C. & S. America	Africa and ME	Asia	Oceania	**Total**
European Union	0.0	0.0	38.4	0.0	114.1	11.2	0.0	0.0	**163.7**
Other Europe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
CIS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
NAFTA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
C. & S. America	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Africa and ME	0.0	0.0	0.0	2.2	0.0	0.0	8.5	0.0	**10.7**
China	0.0	0.0	15.3	16.2	103.0	23.3	60.3	234.9	**453.0**
Japan	0.0	0.0	0.0	0.0	75.9	0.0	0.0	74.8	**150.7**
Other Asia	0.0	0.0	0.0	0.0	49.5	2.4	25.6	4.3	**81.8**
Oceania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**0.0**	**0.0**	**53.7**	**18.3**	**342.5**	**36.9**	**94.4**	**314.1**	**859.9**

Coking coal (2008)

Importers / Exporters	Australia	Canada	Russia	United States	**Total**
Europe and Mediterranean	25.4	7.0	2.1	35.9	**70.5**
Japan	54.9	9.6	3.0	0.0	**67.4**
Korea	16.2	0.0	0.0	0.0	**16.2**
China	0.0	0.0	0.0	0.0	**0.0**
India	34.1	0.0	0.0	0.0	**34.1**
Other Asia	8.7	0.0	0.0	0.0	**8.7**
Brazil	11.9	0.5	0.0	0.0	**12.4**
Other	2.4	6.1	0.0	0.0	**8.6**
Total	**153.7**	**23.3**	**5.1**	**35.9**	**218.0**

Iron ore (2009)

Importers / Exporters	European Union	Other Europe	CIS	NAFTA	C. & S. America	Africa and ME	Asia	Oceania	**Total**
European Union	0.0	0.0	25.0	18.2	36.7	10.3	0.0	0.0	**90.2**
Other Europe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
CIS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
NAFTA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
C. & S. America	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Africa and ME	0.0	0.0	0.0	1.5	4.3	0.0	0.0	0.0	**5.7**
China	0.0	0.0	28.6	0.0	190.9	34.3	84.0	372.0	**709.8**
Japan	0.0	0.0	0.0	0.0	110.7	0.0	0.0	0.0	**110.7**
Other Asia	0.0	0.0	0.0	0.0	55.5	3.8	0.0	15.0	**74.3**
Oceania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**0.0**	**0.0**	**53.6**	**19.7**	**398.1**	**48.4**	**84.0**	**387.0**	**990.6**

Coking coal (2009)

Importers / Exporters	Australia	Canada	Russia	United States	**Total**
Europe and Mediterranean	5.7	0.0	4.8	36.1	**46.6**
Japan	34.3	18.2	3.2	0.0	**55.7**
Korea	21.4	0.0	0.0	0.0	**21.4**
China	33.6	0.0	0.0	0.0	**33.6**
India	32.9	0.0	0.0	0.0	**32.9**
Other Asia	4.2	0.0	0.0	0.0	**4.2**
Brazil	10.0	0.6	0.0	3.0	**13.6**
Other	0.7	5.5	0.0	0.0	**6.2**
Total	**142.9**	**24.3**	**8.0**	**39.0**	**214.2**

Iron ore (2010)

Importers / Exporters	European Union	Other Europe	CIS	NAFTA	C. & S. America	Africa and ME	Asia	Oceania	**Total**
European Union	0.0	0.0	24.4	21.0	86.9	11.3	0.0	0.0	**143.7**
Other Europe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
CIS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
NAFTA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
C. & S. America	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Africa and ME	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	**6.0**
China	0.0	0.0	25.9	0.0	94.6	34.2	96.4	400.8	**651.9**
Japan	0.0	0.0	0.0	0.0	127.1	0.0	0.0	5.4	**132.5**
Other Asia	0.0	0.0	0.0	0.0	72.6	6.4	4.9	27.5	**111.4**
Oceania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**0.0**	**0.0**	**50.3**	**21.0**	**387.2**	**51.9**	**101.3**	**433.8**	**1045.4**

Coking coal (2010)

Importers / Exporters	Australia	Canada	Russia	United States	**Total**
Europe and Mediterranean	19.7	0.0	1.7	39.2	**60.5**
Japan	35.6	22.2	3.6	0.0	**61.4**
Korea	27.6	0.0	0.0	0.0	**27.6**
China	38.1	0.0	0.0	0.0	**38.1**
India	39.4	0.0	0.0	0.0	**39.4**
Other Asia	8.7	0.0	0.0	0.0	**8.7**
Brazil	2.8	0.8	0.0	10.3	**13.9**
Other	0.4	2.3	0.0	0.0	**2.7**
Total	**172.3**	**25.2**	**5.3**	**49.5**	**252.4**

Table E.3: Separate optimisation: Iron ore and coking coal trade flows in million tonnes (demand elasticity of -0.5)

Iron ore (2008)

Importers / Exporters	European Union	Other Europe	CIS	NAFTA	C. & S. America	Africa and ME	Asia	Oceania	**Total**
European Union	0.0	0.0	38.4	0.0	48.5	14.3	6.5	47.1	**154.8**
Other Europe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
CIS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
NAFTA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
C. & S. America	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Africa and ME	0.1	0.0	0.0	2.2	1.2	0.0	4.1	2.1	**9.6**
China	8.1	0.0	15.3	16.2	166.1	12.5	38.7	188.4	**445.3**
Japan	3.7	0.0	0.0	0.0	28.5	6.1	42.1	53.6	**134.0**
Other Asia	0.8	0.0	0.0	0.0	24.2	3.9	24.3	23.0	**76.3**
Oceania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**12.8**	**0.0**	**53.7**	**18.3**	**268.6**	**36.8**	**115.8**	**314.1**	**820.0**

Coking coal (2008)

Importers / Exporters	Australia	Canada	Russia	United States	**Total**
Europe and Mediterranean	27.5	16.8	2.1	12.2	**58.7**
Japan	49.5	0.3	3.0	6.6	**59.4**
Korea	12.7	0.0	0.0	1.6	**14.3**
China	3.6	0.0	0.0	0.0	**3.6**
India	22.8	0.0	0.0	5.4	**28.2**
Other Asia	3.5	3.0	0.0	1.0	**7.5**
Brazil	4.0	0.0	0.0	6.2	**10.2**
Other	3.7	2.6	0.0	1.3	**7.6**
Total	**127.4**	**22.7**	**5.1**	**34.3**	**189.4**

Iron ore (2009)

Importers / Exporters	European Union	Other Europe	CIS	NAFTA	C. & S. America	Africa and ME	Asia	Oceania	**Total**
European Union	0.0	0.0	25.0	26.1	28.0	4.3	0.0	10.2	**93.6**
Other Europe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
CIS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
NAFTA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
C. & S. America	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Africa and ME	0.0	0.0	0.0	1.5	1.5	0.0	1.5	0.9	**5.4**
China	12.1	0.0	28.6	0.0	171.1	32.5	86.4	298.0	**628.9**
Japan	2.0	0.0	0.0	1.6	32.4	5.2	0.0	59.0	100.2
Other Asia	0.9	0.0	0.0	0.0	34.3	6.3	5.5	19.8	**66.8**
Oceania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**15.1**	**0.0**	**53.6**	**29.2**	**267.4**	**48.3**	**93.5**	**387.9**	**894.9**

Coking coal (2009)

Importers / Exporters	Australia	Canada	Russia	United States	**Total**
Europe and Mediterranean	16.6	10.9	4.8	7.9	**40.2**
Japan	30.8	10.2	3.2	4.8	**49.0**
Korea	16.6	0.0	0.0	2.0	**18.6**
China	13.5	0.0	0.0	4.8	**18.2**
India	22.8	0.0	0.0	5.9	**28.7**
Other Asia	2.0	0.9	0.0	0.6	**3.5**
Brazil	4.1	0.0	0.0	7.8	**11.9**
Other	2.6	1.7	0.0	0.8	**5.1**
Total	**108.9**	**23.8**	**8.0**	**34.6**	**175.3**

Iron ore (2010)

Importers / Exporters	European Union	Other Europe	CIS	NAFTA	C. & S. America	Africa and ME	Asia	Oceania	**Total**
European Union	0.0	0.0	32.5	8.0	50.6	9.0	0.0	58.1	**158.2**
Other Europe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
CIS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
NAFTA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
C. & S. America	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Africa and ME	0.1	0.0	0.0	0.0	3.9	0.0	0.7	1.2	**5.9**
China	12.2	0.0	25.9	0.0	188.8	23.3	102.7	264.7	**617.5**
Japan	4.4	0.0	0.0	14.1	36.3	8.2	0.0	65.9	**129.0**
Other Asia	2.6	0.0	0.0	0.0	42.1	11.2	5.3	45.3	**106.6**
Oceania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**19.3**	**0.0**	**58.4**	**22.0**	**321.7**	**51.7**	**108.7**	**435.3**	**1017.1**

Coking coal (2010)

Importers / Exporters	Australia	Canada	Russia	United States	**Total**
Europe and Mediterranean	22.6	12.2	4.9	16.0	**55.6**
Japan	39.9	8.4	3.6	5.4	**57.3**
Korea	23.4	0.0	0.0	2.4	**25.8**
China	24.2	0.0	0.0	8.7	**32.9**
India	31.1	0.0	0.0	5.1	**36.1**
Other Asia	3.1	4.0	0.0	1.0	**8.1**
Brazil	3.9	0.0	0.0	9.1	**13.0**
Other	1.8	0.0	0.0	0.6	**2.3**
Total	**149.9**	**24.5**	**8.5**	**48.3**	**231.2**

Table E.4: Simultaneous optimisation: Iron ore and coking coal trade flows in million tonnes (demand elasticity of -0.5)

Iron ore (2008)

Importers / Exporters	European Union	Other Europe	CIS	NAFTA	C. & S. America	Africa and ME	Asia	Oceania	**Total**
European Union	0.0	0.0	38.4	0.0	46.9	16.3	1.4	57.7	**160.6**
Other Europe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
CIS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
NAFTA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
C. & S. America	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Africa and ME	0.1	0.0	0.0	2.2	1.3	0.0	3.5	2.7	**9.8**
China	8.7	0.0	15.3	16.2	171.4	6.2	61.3	163.8	**442.8**
Japan	4.0	0.0	0.0	0.0	30.5	9.9	27.8	64.4	**136.6**
Other Asia	0.9	0.0	0.0	0.0	25.0	4.6	19.7	27.0	**77.3**
Oceania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**13.7**	**0.0**	**53.7**	**18.3**	**275.1**	**36.9**	**113.7**	**315.6**	**827.1**

Coking coal (2008)

Importers / Exporters	Australia	Canada	Russia	United States	**Total**
Europe and Mediterranean	29.0	17.4	2.1	12.1	**60.6**
Japan	51.5	0.0	3.0	6.1	**60.6**
Korea	13.1	0.0	0.0	1.5	**14.6**
China	17.1	0.0	0.0	0.0	**17.1**
India	24.1	0.0	0.0	4.9	**29.1**
Other Asia	4.6	2.1	0.0	1.0	**7.7**
Brazil	4.9	0.0	0.0	5.6	**10.6**
Other	3.3	3.2	0.0	1.2	**7.7**
Total	**147.7**	**22.7**	**5.1**	**32.4**	**207.9**

Iron ore (2009)

Importers / Exporters	European Union	Other Europe	CIS	NAFTA	C. & S. America	Africa and ME	Asia	Oceania	**Total**
European Union	0.0	0.0	25.0	17.4	27.7	7.4	0.0	17.2	**94.6**
Other Europe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
CIS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
NAFTA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Central and South America	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Africa and Middle East	0.0	0.0	0.0	1.5	1.5	0.0	1.3	1.1	**5.3**
China	12.1	0.0	28.6	0.0	178.4	24.4	86.5	302.4	**632.4**
Japan	2.0	0.0	0.0	9.9	37.3	8.5	0.0	44.1	**101.7**
Other Asia	0.9	0.0	0.0	0.0	31.2	8.1	4.4	23.0	**67.6**
Oceania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**15.1**	**0.0**	**53.6**	**28.7**	**276.2**	**48.2**	**92.1**	**387.8**	**901.7**

Coking coal (2009)

Importers / Exporters	Australia	Canada	Russia	United States	**Total**
Europe and Mediterranean	17.7	11.6	4.8	6.6	**40.7**
Japan	33.1	9.2	3.2	4.0	**49.5**
Korea	17.2	0.0	0.0	1.7	**18.8**
China	34.6	0.0	0.0	1.2	**35.8**
India	24.4	0.0	0.0	5.0	**29.3**
Other Asia	2.7	0.3	0.0	0.5	**3.6**
Brazil	4.5	0.0	0.0	7.5	**12.0**
Other	1.8	2.7	0.0	0.7	**5.2**
Total	**135.9**	**23.8**	**8.0**	**27.3**	**195.0**

Iron ore (2010)

Importers / Exporters	European Union	Other Europe	**CIS**	NAFTA	C. & S. America	Africa and ME	Asia	Oceania	**Total**
European Union	0.0	0.0	29.5	8.7	53.8	11.4	0.0	58.1	**161.5**
Other Europe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
CIS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
NAFTA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Central and South America	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Africa and Middle East	0.1	0.0	0.0	0.0	3.9	0.0	0.7	1.2	**5.9**
China	12.4	0.0	25.9	3.0	201.2	17.0	101.5	263.9	**624.8**
Japan	4.4	0.0	0.0	12.4	39.3	10.6	0.0	64.8	**131.5**
Other Asia	2.6	0.0	0.0	0.0	41.9	12.8	4.1	46.9	**108.3**
Oceania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**19.5**	**0.0**	**55.4**	**24.0**	**340.2**	**51.7**	**106.3**	**434.9**	**1032.1**

Coking coal (2010)

Importers / Exporters	Australia	Canada	Russia	United States	**Total**
Europe and Mediterranean	26.7	13.2	3.7	13.7	**57.3**
Japan	41.8	8.7	3.6	4.4	**58.5**
Korea	24.4	0.0	0.0	2.0	**26.3**
China	30.6	0.0	0.0	5.7	**36.3**
India	33.1	0.0	0.0	4.1	**37.2**
Other Asia	5.4	2.1	0.0	0.8	**8.3**
Brazil	4.6	0.0	0.0	8.7	**13.3**
Other	1.2	0.7	0.0	0.5	**2.5**
Total	**167.9**	**24.7**	**7.3**	**39.8**	**239.7**