Institute of Energy Economics
at the University of Cologne

EWI Working Paper, No. 11/02

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April 2011

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Abstract

The seaborne steam coal market changed in recent years. Trade volumes grew dynamically, important players emerged and since 2007 prices increased significantly and remained relatively high since then. In this paper we analyse market equilibria in the years 2006 and 2008 by testing for two possible market structure scenarios in this market: perfect competition and an oligopoly setup with major exporters competing in quantities. We conclude from our results that international steam coal trade is not perfectly competitive as there is a large spread between marginal costs and prices and a low capacity utilisation in 2008. Further, trade flows are generally more diversified in reality than in the competitive scenario. However, also the Cournot scenarios fail to accurately explain real market outcomes. We conclude that only more sophisticated models of strategic behaviour can predict market equilibria in international steam coal trade.

Keywords: Steam coal trade, mining costs, market structure

JEL classification: C61, L11, L71, Q31

ISSN: 1862 3808

[♦] We would like to thank Stefan Lochner, Felix Höffler and Timo Panke for their helpful comments and suggestions. This paper also benefited from comments of the participants of the 2010 European IAEE Conference in Vilnius and the 8th Workshop of the Student Chapter of the GEE at the Centre of European Economic Research (ZEW) in Mannheim.

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1. Introduction

Behind oil but before natural gas, coal is the second most important primary energy source. It is mainly used for electricity and heat generation. About 36% of the global electricity generation is based on hard coal.[1] Although most of the coal is produced and consumed domestically, international steam coal trade is on the rise.[2] However, price volatility increased too and the years 2007 and 2008 both saw unprecedented price spikes. Steam coal prices in North Western Europe reached a maximum of 210 USD/t in mid-2008 and averaged 147 USD/t for the whole year. This is more than 130% above the average price of 64 USD/t in 2006.[3] Prices decreased with the financial crisis in the second half of 2008 but remained on relatively high levels through 2009 and 2010.[4]

These price increases on the spot markets for internationally traded coal in recent years were paralleled by significant structural changes on the demand and the supply side. During the last decade demand increased dynamically and total trade volume grew by more than 60% between 2000 and 2009 on the seaborne market. This development is mainly caused by a strong growth of energy demand in Asian economies. Recently, India and South East Asian economies have become major importers in the Pacific market. Moreover, China a major net exporter at the beginning of the last decade has drastically increased imports since 2005.

The supply side is dominated by countries with a mainly export oriented mining industry like South Africa, Australia, Indonesia and Colombia. The latter two are relatively new players on this market which expanded their supply capacity quickly during the last decade. Moreover, in some countries the government has put its focus on developing national coal strategies in the last years, often tightening their control of coal exports, for instance in China or Indonesia.[5] Due to governmental control in some countries or the influence of large company consortia and industry associations in other countries, steam coal supply tends to be aggregated on a national level rather than on a firm level.

Given the growing importance of several new suppliers, the emergence of national energy and coal strategies in several countries and the dramatic recent steam coal price evolutions we test if market structures in 2006 and 2008 can be described either by a competitive setup or an

[1] See IEA (2010b). Data for 2008.

[2] The classification of hard coal (distinct from lignite) comprises steam coal and coking coal. Steam coal (or thermal coal) is mainly used in electricity generation whereas coking coal is used for metallurgical purposes.

[3] See Ritschel (2009).

[4] The Asian marker (North Western European marker) was 79 USD/t (70 USD/t) in 2009 and 105 USD/t (92 USD/t) in 2010.

[5] China constantly reduced export licenses (from 80 mt in 2005 to less than 20 mt in 2011). Further, the Chinese government started a programme to restructure and consolidate the coal mining industry (Peng 2010). In Indonesia only Indonesian companies or consortia are eligible for mining concessions (Baruya 2009).

oligopolistic setup. To do so, we develop an optimisation model for computing spatial market equilibria in competitive and oligopolistic international trade markets. The equilibrium modelling approach was introduced by Samuelson (1952) with his work on the programming of competitive equilibria in spatial markets, and generalised for various non-competitive market structure scenarios e.g. by Takayama and Judge (1964, 1971), Harker (1984, 1986) and Yang et al. (2002). The model is implemented as a mixed complementarity programme (MCP) with the software GAMS and based on a unique coal market dataset of EWI. This dataset comprises inter alia supply capacities and costs including time dependent supply cost functions based on input price evolutions to account for recent supply cost increases.

We find that actual prices in 2006 are in line with the competitive benchmark in Europe but prices in Asian importing regions exceed marginal costs. In 2008, prices and volumes are not consistent with the competitive benchmark. Furthermore, trade flows are more diversified in the real market than in the competitive scenario. However, also for both years, actual prices were lower than the oligopolistic prediction. Generally, the results indicate that competitive models are not able to fully reproduce coal market equilibria, particularly in 2008. This suggests that the degree of competition may recently have decreased in the coal trade market.

Literature on market conduct in international steam coal trade is relatively scarce. Abbey and Kolstad (1983) present a qualitative analysis of the potentials to exert market power in steam coal trade. Kolstad and Abbey (1984) were the first to quantitatively analyse strategic behaviour in international steam coal trade in the early 1980s using an MCP model. Besides perfect competition they model various imperfect market structures. The authors find that a non-competitive market structure consisting of a duopoly and a monopsony simulates the actual trade patterns well. However, since then the steam coal trade market has changed substantially. We follow the approach of Kolstad and Abbey (1984) by using an MCP model and update their research with recent data. The paper most closely related to ours is Haftendorn and Holz (2010). They model a number of major seaborne coal trade routes and apply a mixed complementarity model to test if trade volumes on these routes fit competitive or Cournot-Nash behaviour in the years 2005 and 2006. They conclude from their results that the steam coal trade market is better represented by perfect competition.

We add to their analysis three important aspects. First, while their research focuses on selected major trade routes, we extend the analysis to cover the full seaborne steam coal trade market. Second, we use a different database and generalise the model for multi-plant players to account for cost-differences in mining regions and mining technologies. It is reassuring that for 2006 we find, in an independent approach, qualitatively similar results as Haftendorn and

Holz (2010). Third, and most important, by extending the time considered up to 2008, we are able to detect a change in market structure from competitive outcomes in 2006 to non-competitive outcomes in 2008.

The remainder of the paper is structured as follows: First, we will briefly outline the current situation on the seaborne steam coal trade market. Section three proceeds with a detailed description of the model and its properties. Then, in section four the supply and demand side data input is described. The scenario design is outlined in section five. Section six presents the model results and finally, section seven concludes the paper.

2. The seaborne steam coal trade market

The majority of steam coals are not traded internationally but are produced and consumed in domestic markets. In 2008 total global hard coal production was 5850 mt.[6] The two largest domestic markets are China and the USA together comprising more than 65% of total production. About 13% of the global steam coal production is traded internationally and more than 90% of international steam coal trade is seaborne. In this submarket two different types of suppliers interact with each other: Countries that have a dedicated export-oriented mining industry and countries with chiefly inland-oriented mining industries. [7] The former type primarily comprises South Africa, Colombia, Australia and Indonesia and holds most of the supply capacity for the international trade market. These export industries usually have a cost advantage over domestic industries due to good coal qualities, low mining costs and economical access to transport infrastructure. The latter type primarily consists of China, USA and Russia. These countries have some dedicated export collieries but most of the potential *export* capacity can serve both the national and the international market. Depending on the relation of export prices to domestic prices these mines supply either domestic consumers or maritime trade markets (swing suppliers). The majority of domestic mines are always extramarginal on international markets due to low coal quality, contractual obligations, high supply costs or the lack of access to infrastructure.

The seaborne trade market can be divided into a Pacific and an Atlantic market region.[8] Major importing regions in the Atlantic market are the USA and Europe (including neighbouring Mediterranean countries) with the United Kingdom and Germany at the top. Traditionally these importing regions are primarily supplied by South Africa, Colombia and Russia.

[6] See Ritschel (2009), includes coking coal.
[7] See e.g. Kopal (2007) or Rademacher (2008).
[8] During the last decade trade flows between the two regions grew considerably and recent research has pointed out that the global steam coal market is well integrated (see e.g. Warrell (2006) or Li (2008)). Nevertheless we use these terms in this paper in a geographical sense to better structure our analysis.

The Pacific market has grown more dynamically in recent years. High quantities are imported by Japan, South Korea and Taiwan – all three of them having virtually no indigenous coal production and therefore heavily rely on imports. However, most of the growth has come from emerging import regions like India, South East Asia and China. The supply side is dominated by Australia and Indonesia although the sustained high prices in Asia have attracted increasing spot volumes from South Africa and very recently also from Colombia.

3. Model Description

We develop a spatial equilibrium model for the seaborne steam coal market in which exporters and importers trade with each other. Coal exporters control one or more coal production regions (including the infrastructure) and coal importers are assigned to demand regions. These players trade steam coal with each other via bulk carrier shipping routes. It is assumed that the exporters' objective is to maximise their respective profits. Importers are assumed to act as price takers. The optimisation model is formulated as a mixed complementary problem (MCP) by deriving the Karush-Kuhn-Tucker (KKT) conditions. In equilibrium, the set of prices and quantities simultaneously satisfies all maximisation conditions.

The model consists of a network *NW(N,A)*, where *N* is a set of nodes and *A* is set of arcs between the nodes. The set of nodes *N* can be divided into two subsets $N \equiv E \cup I$, where $i \in E$ is an export region and $j \in I$ is a demand node. Players $z \in Z$ control export regions $i \in E_z$. Export regions can only be controlled by one player $\bigcap_{z \in Z} E_z \equiv \emptyset$. The set of arcs $A \equiv E_z \times I$ consists of arcs $f_{(z,j)}$. Table 1 gives an overview over demand regions, export regions and the corresponding players as modelled in this paper.[9]

[9] The model export nodes cover about 98% of real market exports. The remaining 2% of exports is divided among the model regions according to their share of total production. Import side coverage is about 95%. The import balance is divided among the import regions according to their share of total imports.

Table 1: Model regions

Exporting regions	*Corresponding players*	*Demand regions*
New South Wales/open cast	Australia	Europe (including Mediterranean)
New South Wales/underground	Australia	Japan
Queensland/open cast	Australia	South Korea
Queensland/underground	Australia	Taiwan
Mpumalanga/open cast	South Africa	China
Mpumalanga/underground	South Africa	India
Kalimantan & Sumatra	Indonesia	Latin America
Kuzbass & Donbass	Russia	North America
Eastern Kuzbass, Yakutia and far East	Russia	South East Asia
Colombia	Colombia	
Shanxi	China	
Central Appalachia	USA	
Venezuela	Venezuela	
Vietnam	Vietnam	
Poland	Poland	
Spitsbergen	Norway	

Mining costs, average inland transport costs and port terminal costs add up to a quadratic FOB (free-on-board) supply function[10] depending on the produced quantity q_i per export node $S_i(q_i)$. Seaborne transport costs $\tau_{z,j}$ per unit $x_{z,j}$ shipped. However, the transport cost parameter $\tau_{z,j}(d_{zj})$ depends on the distance d_{zj} between *z* and *j*. Individual transport cost functions were calculated for every year based on historical data.[11] Import demand is represented by a linear function of the form:

$$p_j\left(\sum_z x_{z,j}\right) = a_j - b_j \cdot \sum_z x_{z,j} \tag{1}$$

Where p_j denotes the price in region *j* subject to the imported quantity. The parameter a_j denotes the reservation price and the parameter b_j specifies the slope of the demand function. Production costs W_i in node $i \in E$ correspond to the integral under the quadratic FOB (free-on-board) supply function:

$$W_i(q_i) = \int_0^{q_i} S_i(q)\,dq = \frac{1}{3}\cdot\alpha_i \cdot q_i^3 + \frac{1}{2}\cdot\beta_i\cdot q_i^2 + \rho_i \cdot q_i \tag{2}$$

[10] Quadratic marginal functions had the best fit when regressed against a dataset of mining costs. Further, quadratic marginal cost functions capture important characteristics of steam coal supply e.g. an increasing increment of marginal costs the more capacity is utilized.

[11] Bulk carrier freight data were provided by McCloskey Coal Information, Frachtkontor Junge & Co, and Baltic Exchange. See section 4.2 for a detailed description of transport cost data.

The amount of coal supplied by player $z \in Z$ to region $j \in I$ is defined as $x_{z,j}$, let us define $\tilde{x}_{z,j}$ as the quantity supplied by all other producers to region $j \in I$:

$$\tilde{x}_{z,j} = \sum_{\substack{k \in Z \\ k \neq z}} x_{k,j} \tag{3}$$

Producer *z*'s profit maximisation problem Ω_z consists of the objective function F_z and the constraints (5) – (7):

$$F_z = \sum_j p_j \left(\tilde{x}_{z,j} + x_{z,j}\right) \cdot x_{z,j} - x_{z,j} \cdot \tau_{z,j} - W_i(q_i) \quad \rightarrow \quad \max_{x,q}! \tag{4}$$

Subject to:

$$\sum_i q_i \geq \sum_j x_{z,j} \quad (\mu_z) \tag{5}$$

$$C_i \geq q_i \quad (\gamma_i) \tag{6}$$

$$q_i \geq 0 \tag{7}$$

Restriction (5) states that production in $i \in E$ has to be at least as high as total exports. The second restriction (6) ensures that production in $i \in E$ does not exceed the available capacity C_i. The strictly quasi-concave objective function (4) and the convex restrictions (5)-(7) form an optimisation problem, which has a unique solution. The first order optimality conditions are thus necessary and sufficient for deriving a unique optimum if the set of feasible solutions is non-empty. The equilibrium conditions are derived using the first order derivatives of the Lagrangian of Ω_z (KKT conditions). The Lagrangian multipliers μ_z and γ_i are shadow prices for player $z \in Z$ and in region $i \in E$ respectively. The variable μ_z represents the value of a marginal unit of exports whereas γ_i corresponds to the value of a marginal unit of production capacity. The KKT conditions can be expressed as follows:

$$\tau_{i,j} - \left(\frac{\partial p_j}{\partial x_{z,j}} + \frac{\partial p_j}{\partial \tilde{x}_{z,j}} \frac{\partial \tilde{x}_{z,j}}{\partial x_{z,j}} \right) x_{z,j} - p_j + \mu_z \geq 0 \perp x_{z,j} \geq 0 \tag{8}$$

$$\frac{\partial W_i}{\partial q_i} + \gamma_i - \mu_z = \alpha_i \cdot q_i^2 + \beta_i \cdot q_i + \rho_i + \gamma_i - \mu_z \geq 0 \perp q_i \geq 0 \tag{9}$$

$$-\sum_j x_{z,j} + \sum_i q_i \geq 0 \perp \mu_z \geq 0 \tag{10}$$

$$-q_i + C_i \geq 0 \perp \gamma_i \geq 0 \tag{11}$$

The derivative $(\partial p_j / \partial x_{z,j} + \partial p_j / \partial \tilde{x}_{z,j} \cdot \partial \tilde{x}_{z,j} / \partial x_{z,j}) \cdot x_{z,j}$ in (8) expresses player *z*'s ability to influence the market price in $j \in I$ by strategically choosing the amount of coal supplied, subject to his conjecture of the other producers‘ reaction. In the case of a Cournot-Nash oligopoly, $\partial\tilde{x}_{z,j}/\partial x_{z,j} = 0$ holds and KKT-condition (8) simplifies to (8a) under the assumption of a linear demand function. In a competitve market, however, a change of player *z*'s supply will be fully offset by the other producers and therefore $\partial\tilde{x}_{z,j}/\partial x_{z,j} = -1$ holds. In the case of perfect competition and for fringe suppliers condition (8) simplifies to (8b).

$$\tau_{z,j} - a_j - 2b_j \cdot x_{z,j} + \mu_z \geq 0 \perp x_{z,j} \geq 0 \tag{8a}$$

$$\tau_{z,j} - a_j - b_j \cdot x_{z,j} + \mu_z \geq 0 \perp x_{z,j} \geq 0 \tag{8b}$$

Equation (1), the first order conditions (8) and (9) as well as capacity constraints (10) and (11) for all players $z \in Z$ together constitute the optimisation problem. The unique solution for this set of inequalities yields the equilibrium for this market. This mixed complementary problem was implemented using the software GAMS.[12]

4. Dataset

The database used in this analysis stems from several extensive research projects conducted at the Institute of Energy Economics at the University of Cologne. Steam coal market data has been acquired from a multitude of different and potentially heterogeneous sources. Although steam coal market data seems scarce at a first glance, various institutions, researchers, experts and companies have published useful information. General steam coal market data is for example published by institutions like IEA and EIA.[13] Detailed data on supply chain costs, steam coal demand and production of major players are available from the IEA Clean Coal Centre.[14] Further publications include analyses from employees working for international utilities and coal industry newsletters.[15] National statistics bureaus and ministries concerned with minerals, energy and resources provide detailed information.[16] Furthermore, company annual reports and presentations related to the steam coal market have been evaluated and expert interviews conducted. Moreover, our database is regularly discussed and reviewed with industry experts.

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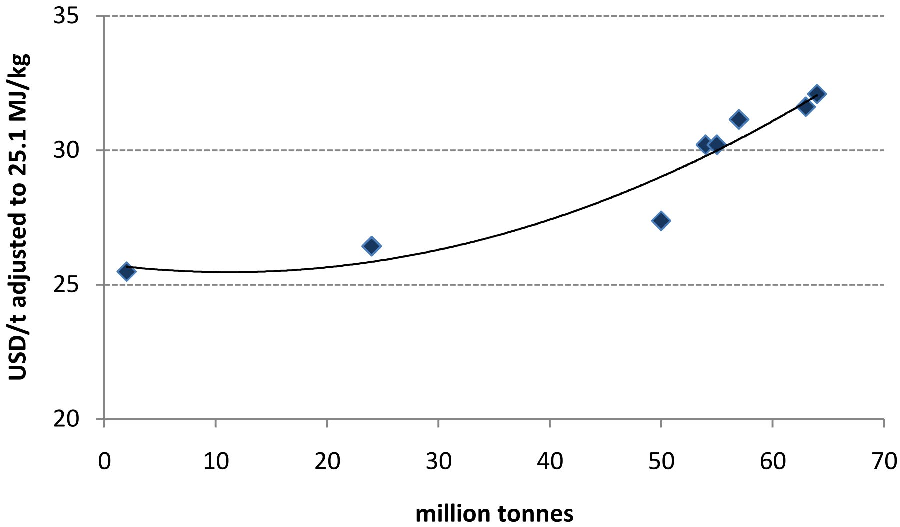
[12] See Rutherford (1994) or Ferris and Munson (1998) for detailed information on complementary programming in GAMS.
[13] See IEA (2009) and IEA (2010a), EIA (2009) and EIA (2010).
[14] See Baruya (2007, 2009), Minchener (2004, 2007) and Crocker/Kowalchuk (2008).
[15] See e.g. Kopal (2007), Rademacher (2008), Bayer et al. (2009) and Ritschel/Schiffer (2005, 2007). The McCloskey Coal Report is regularly reviewed.
[16] Notable examples are ABARE, US Geological Survey, Bundesanstalt für Geowissenschaften und Rohstoffe, Australian Bureau of Statistics, DANE, BLS and Statistics South Africa.

4.1 Mining costs and export capacity

Costs for mining consist of overburden removal and extraction costs, processing and washing costs as well as transportation costs within the colliery. The data on mining costs is based on expert interviews and the evaluation of annual reports and literature sources as described above. Since this data stems from heterogeneous sources and is mostly based on cost ranges and mining costs of representative mines we regard our data only as a proxy for real mining costs. The lack of data on some mines might cause distortions if we would model every single mine explicitly. Therefore we fit the available data of mine mouth cash costs and mining capacity to a quadratic marginal cost function by ordinary least squares. This method yields a supply curve that comprises the main characteristics and cost levels of each mining region. Figure 1 gives an example of Colombian mining costs and the approximated marginal cost function. As coal qualities vary between the mining regions, calorific values are generally adjusted to 25.1 MJ/kg using data from Ritschel (2010), BGR (2009) and IEA (2009).

Figure 1: Example of FOB costs for Colombia and approximation of marginal cost function for 2006



Source: EWI coal market database

These supply curves are complemented by country and technology specific mining cost structures and escalated using input price data. These cost structures are derived from a number of sources. Detailed information for Australian open cast and underground mines is found in ABS (2006). Meister (2008), Baruya (2007) and Ritschel/Schiffer (2007) for instance provide information on cost structures on a global scale. Longwalling and Room/Pillar are the predominant underground mining technologies whereas open cast operations rely either on draglines or truck/shovel or a mix of both technologies. The cost structures indicate how much diesel fuel, steel, explosives, tyres, chemicals, electricity and labour is used per technology. The proportions of these commodities vary significantly between the four predominant extraction technologies dragline, truck/shovel, longwalling and room/pillar (see table 2). Labour costs are one of the factors that typically differ between the coal producing countries. While salaries are low in countries like South Africa or Indonesia they are considerably higher in the USA or Australia.

Table 2: Input factors and relative importance in coal mining in 2006

in %	*Diesel fuel and lubricants*	*Explosives*	*Tyres*	*Steel mill products*	*Electricity*	*Labour*	*Industrial Chemicals*
Room/Pillar	5-8	0-2	0	24-35	10-18	28-39	8-13
Longwalling	5-10	0-2	0	24-35	10-18	28-45	4-8
Dragline	14-18	15-20	5-10	22-28	5-12	18-32	1-4
Truck/Shovel	18-26	17-22	8-12	19-26	0-3	18-35	1-4

Source: ABS (2006), Meister (2008), own database, see also Paulus and Trüby (2010)

The mining cost curves are escalated according to the cost structures using price index data for the above mentioned commodities from various statistical offices. Furthermore, productivity figures and country specific exposures to fluctuations of exchange rates are included. This method yields the shifts in supply curves for the period 2006-2008.

Generally, coal supply costs increased world-wide during 2006 and 2008 due to input price escalation. Table 3 presents an overview of the cost increases for the model mining regions. Clearly, mining cost escalation affected producers differently. Major exporters with a large share of open cast production like Indonesia or Colombia generally experienced higher cost increases. Producers with a high proportion of underground mines like the U.S., South Africa or Australia were less affected. This is due to the different cost structures of underground mining operations. Underground mining technologies rely to a larger proportion on labour costs and electricity prices and other locally sourced materials. Except for steel products which are also an important input in deep mining, the increasing prices of fuel and oil derivatives, explosives and tyres did not raise underground mining costs.

Table 3: Average FOB costs in USD/t and export capacity (adjusted to 25.1 MJ/kg)

	Average costs			Export capacity		
	2006	*2008*	*cost increase*	*2006*	*2008*	*capacity increase*
Indonesia	33	44	33%	154	197	28%
Colombia	31	42	34%	59	74	25%
China (Shanxi)	34	44	30%	62	45	-27%
USA (Central Appalachia)	46	57	23%	25	31	25%
Venezuela	32	38	19%	9	9	0%
Vietnam	29	38	32%	27	22	-18%
Spitsbergen	41	52	26%	2	4	67%
Queensland/open cast	33	41	24%	33	37	13%
Queensland/underground	33	37	14%	8	8	5%
New South Wales/open cast	34	42	23%	52	59	12%
New South Wales/underground	34	41	21%	27	31	15%
South Africa/open cast	28	36	28%	45	46	4%
South Africa/underground	32	41	25%	24	25	5%
Russia (Baltic)	48	64	34%	61	69	14%
Russia (Pacific)	40	48	19%	15	19	22%
Poland	58	79	36%	8	5	-38%
Total				*611*	*681*	12%

Source: own calculations/EWI coal market database; export capacity data based on Kopal (2007), Rademacher (2008) and Bayer et al. (2009)

Steam coal export capacity increased by about 12% between 2006 and 2008 (table 3). In the Pacific basin much of the growth came from Indonesia and Australia expanding their supply capacity. In the Atlantic market Colombia increased its export capacity by about 25 mt and became the largest steam coal exporter in the Atlantic market in 2008. Export capacity data was primarily derived from Kopal (2007), Rademacher (2008) and Bayer et al. (2009) and adjusted for energy content.

4.2 Transport costs, port handling fees and seaborne freight rates

Inland transport costs depend on the transportation mode and the distance from the coal fields to the export terminal. Coal is mainly hauled by rail or truck and in some cases by river barge. Inland transport costs vary between the mining regions. While they are below 4 USD/t for the bulk of the Colombian production they may be as high as 25 USD/t for the transport from the Russian Kuzbass basin to the Baltic ports. We estimated the relative impact of diesel fuel and electricity cost escalation by the relative importance of truck and railway haulage for main transport routes. Port handling fees comprise costs for unloading, storage and loading onto vessels. Country specific average inland transport cost and port handling fees are added to the mining cost curve to derive FOB supply functions. Seaborne bulk carrier freight rates are a major cost component of internationally traded steam coal. For determining seaborne transport costs we use logarithmic freight cost functions based on distance which is regressed against a dataset of freight cost observations for both model years. We use these cost functions to determine consistent freight rates for every possible shipping route in the model.

4.3 Demand data

As described in Section 3 we assume linear steam coal demand functions for all importing regions based on reference quantities and prices as well as elasticities (see table 4 for reference volumes).[17] A general shortcoming of the literature on market conduct in global steam coal trade is the treatment of the demand side. Usually, assumptions on elasticities are drawn from empirical analyses found in the literature and subsequently elasticity sensitivities are computed.[18] This paper presents an elasticity analysis for Europe, the largest import demand region on the maritime market. Demand elasticities for other regions are based on an extensive literature review.

Table 4: Steam coal reference demand in million tonnes adjusted to 25.1 MJ/kg

	Europe	*Japan*	*India*	*Latin America*	*China*	*Taiwan*	*Korea*	*North America*	*South East Asia*
2006	187	110	26	9	46	60	62	42	29
2008	184	118	35	16	46	60	72	38	36

Source: IEA (2008, 2010); Ritschel (2007, 2009)

Several econometric analyses on short run steam coal demand elasticities and interfuel substitution have so far been published (see table 5 for an overview of the most important articles). Empirically estimated elasticities fall in range from -0.05 to -0.57. Although, the analyses differ in terms regional coverage, timeframe and methodological approach all authors find that price elasticity of steam coal is inelastic (|Elasticity| < 1).

[17] Reference quantities are based on Ritschel (2007, 2010) and IEA (2007, 2010). We used the MCIS steam coal markers as reference price data in the model.

[18] See e.g. Haftendorn and Holz (2010) who choose elasticities during the calibration process based on Dahl (1993) or Graham et al. (1999) who test for several elasticities figures. Kolstad and Abbey assume demand elasticities of -0.6 for all regions.

Table 5: Overview of short run coal demand elasticities in the literature

Article	*Methodology*	*Time period*	*Sector*	*Region*	*|Elasticity|*
Dahl and Ko (1998)	Panel data analysis	1991-1993	Electricity	U.S.	0.16-0.26
Ko (1993)	Time series analysis	1949-1991	Electricity	U.S.	0.25
Kulshreshta and Parik (2000)	Time series analysis	1970-1995	Electricity	India	0.34
Söderholm (2001)	Panel data analysis	1984-1994	Electricity	Europe	0.05-0.29
Masih and Masih (1996)	Time series analysis	1970-1992	all sectors	China	0.25
Ball and Loncar (1991)	Time series analysis	1978-1988	Electricity	OECD	0.16
Chan and Lee (1997)	Time series analysis	1953-1994	all sectors	China	0.26-0.32
Ko and Dahl (2001)	Panel data analysis	1993	Electricity	U.S.	0.57

Short run steam coal demand elasticity depends on various factors such as the power plant mix, the price of alternative fuels (particularly natural gas and in some regions fuel oil), the price of emission certificates, and total electricity demand to name but a few. Since these factors vary over time it is likely that some of the figures presented in table 5 are outdated today.

We therefore conduct a steam coal demand analysis for Europe using the dispatch module of DIME (Dispatch and Investment Model for Electricity markets in Europe). DIME is large-scale linear optimisation model for the European electricity market that simulates hourly dispatch taking account of conventional and renewable generation technologies.[19] We calibrate the model with actual data for the years 2006 and 2008 including the European power plant fleet, gas, fuel oil and CO_2 emission prices as well as country-specific load data. Then, we iteratively test a high number of (equidistant) steam coal price points. The model computes the cost-minimal power plant dispatch and steam coal consumption subject to the coal price. Subsequently, we fit a linear function to the data using OLS from which we derive the elasticity at the reference point. Steam coal demand elasticity for the European electricity sector is estimated to be -0.12 in 2006 and -0.43 in 2008. The difference between these two figures stems from the varying gas and CO_2 emission prices and thus their impact on the clean dark spread in the reference point.[20] During 2006 the clean dark spread was favourable for coal fired power plants whereas in 2008, with an increasing emissions price and a similar gas price as in 2006 the clean dark spread decreased. Hence, around the reference point (high coal price in 2008; low coal price in 2006) the elasticity was higher in 2008 as in 2006.

[19] See Bartels (2009). For applications of this model see e.g. Paulus and Borggrefe (2010) or Nagl et al. (2011). A detailed description can be obtained from www.ewi.uni-koeln.de.

[20] The clean dark spread is the margin that a coal fired power plant earns given a certain electricity, coal and emissions price. European gas spot market prices were 22 EUR/MWh in 2006 and 24 EUR/MWh in 2008 (APX, 2010). CO_2 emission prices were 17 EUR/tCO_2 in 2006 and 22 EUR/tCO_2 in 2008 (EEX, 2010).

However, these results cannot be generalised for all demand regions since they depend on a number of factors that usually differ regionally.[21] In this paper we use the estimated elasticities for Europe and assume a steam coal demand elasticity of -0.3 for all other importing regions for both years. This assumption is based on the above mentioned literature review.

5. Simulation design

The focus of our analysis is on seaborne steam coal trade for which a spot market with several well established price indices exists.[22] Hence, we model only dedicated export mining capacity.[23]

The supply structure in the steam coal trade market is heterogeneous. It consists of large state-run mining entities, several privately-owned international mining companies and a large number of small national players. Furthermore, production regions are widely dispersed over the globe and so far no formal cartel such as the OPEC has been established. Therefore, in one scenario we test for a competitively organised steam coal trade market.

However, the majority of internationally traded coal is produced by only four countries with a primarily export-oriented mining industry and a favourable cost situation: Indonesia, Australia, South Africa and Colombia. Indonesia has been a member of OPEC until 2008 when its oil reserves were depleted. Within few years it has become the largest steam coal exporter (Indonesian coal exports grew by 45% between 2005 and 2008). The issue of mining concessions is government controlled and nowadays only granted to Indonesian companies.[24] Hence, currently the majority of steam coal production and infrastructure is controlled by large Indonesian conglomerates or the government. International coal trade is an important national revenue earner, which may favour non-competitive behaviour on a government level. Australia, Colombia and South Africa have privately owned mining industries[25] but the crucial export terminals are controlled by consortia consisting of the major players in the

[21] For instance regionally differing gas prices or the installed capacity, availability and efficiency of the fleet. In some regions the competing generating technology may not be gas fired plants. Decreasing or increasing electricity demand also has an impact on coal demand elasticity. Moreover, emissions trading systems are not implemented in all regions (the U.S. for example have no GHG emissions trading system but an NO_x trading system).

[22] See Ekawan and Duchêne (2006).

[23] Export capacity data is based on Kopal (2007) and Rademacher (2008) but adjusted for energy content and in some cases downgraded if other sources suggested so.

[24] See Baruya (2009).

[25] Nevertheless between 65% and 95% of steam coal exports of South Africa, Colombia and Australia are controlled by six large multinational companies (Xstrata, AngloAmerican, BHP Billiton, Rio Tinto and Drummond). See Murray (2007) and Wacaster (2008).

country.[26] Clearly, all of these countries have the *potential* to act strategically and can be interpreted as national oligopolists.

Similar to Kolstad and Abbey (1984), we assume that individual producers act as price takers but oligopolistic rent is accrued on a country level for example through taxes, royalties, quotas or collusive port throughput agreements. This allows us to use aggregate national supply functions.[27] The non-competitive scenario is designed as follows. Australia, Indonesia, Colombia and South Africa act as non-cooperative Cournot players. Additionally China is assumed to act as a Cournot player. China is the largest steam coal producer in the world and has the potential to influence the seaborne market significantly. Chinese politics have intervened regularly in resource markets and have continuously reduced steam coal export quotas.[28] Russia, USA, Venezuela, Vietnam, Norway and Poland act as price takers and constitute the competitive fringe. All of them have a mining industry that primarily serves the domestic market or is very small.

6. Results

6.1 Simulation results for the year 2006

Figure 2 depicts actual price data and simulated model prices for the perfectly competitive and the Cournot oligopoly scenario for four major importing regions.[29] Clearly, the marginal cost based price matches the actual import price in Europe. Actual prices were however higher than marginal costs of delivery in Japan, Taiwan and South Korea. From a price perspective the hypothesis of Cournot-Nash behaviour can be rejected since oligopolistic prices exceed actual prices significantly in 2006.

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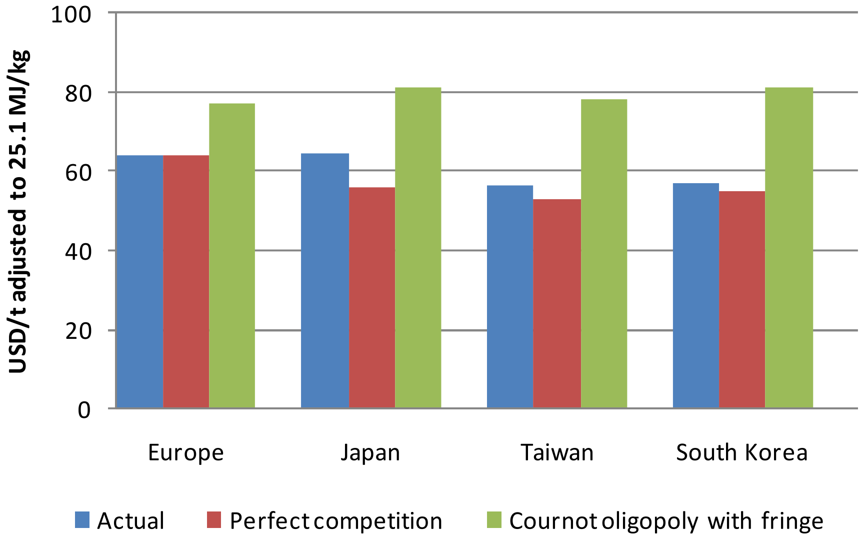
[26] BHP Billiton and AngloAmerican are major shareholders of the Newcastle Infrastructure Group which operates the Newcastle Coal Terminal the main export hub in New South Wales. The largest coal terminal in the world, Richards Bay (South Africa) is jointly owned by all major producers in the country amongst them: BHP Billiton, AngloAmerican and Xstrata. The main export terminal in Colombia, Puerto Drummond and Puerto Bolivar are owned by Drummond and a consortium consisting of Xstrata, BHP-Billiton and AngloAmerican respectively. Moreover, these companies are vertically integrated and also own and operate the domestic coal transport infrastructure (Baruya, 2007).

[27] Our Cournot model formulation can be interpreted as a quota system that restricts exports to the Cournot-Nash outcome. Other Cournot model formulations with taxes instead of quotas of course produce equivalent outcomes (see e.g. Kolstad and Abbey, 1984).

[28] Chinese coal policy shares some interesting similarities with its rare earths policy. Chinese government has introduced an export limit on coal and on rare earths and has repeatedly cut these limits (Sagawa/Koizumi, 2008; Hurst 2010). Moreover, it restructures and consolidates both its coal mining and its rare earths mining industries to gain more control (Peng, 2010; Hurst 2010). In the coal sector companies have to qualify as exporters. So far only state-run companies are eligible for export licences (Baruya, 2007).

[29] For reasons of consistency we use the McCloskey's Asian marker, North West European marker, and Japanese marker for deliveries in the 90 days forward period. These markers are adjusted to 6000 kcal/kg and are a spot price indicator.

Figure 2: Comparison of actual and simulated prices in 2006



Source: own calculations/MCIS-steam coal marker prices

Table 6 reports actual and simulated steam coal trade volumes between exporting and importing regions for the year 2006 in million tonnes. In comparison to the price analysis the picture is less clear-cut when the focus is on trade flows. In general, trade flows in the perfect competition setup fit the actual trade pattern better since total supply is too low in the non-competitive scenario. Main trade relations in the real market match the major importer/exporter relations in the perfectly competitive scenario well in the Atlantic market.[30] This supports the hypothesis that the international steam coal trade market was, to a certain degree, subject to competitive market mechanisms in 2006. However, the actual trade pattern is more diversified than the competitive one, particularly in the Pacific basin.[31]

[30] In reality South Africa, Russia, the U.S. and Colombia are the main suppliers to Europe. Small high cost producers like Poland or Norway are located close to the European market and generally ship their product to Europe. The North American demand region procures most of its imported coals from Latin American suppliers.

[31] Several reasons may explain the deviations between the actual trade pattern and the competitive pattern. First, economies with a high import dependency like Taiwan, Japan or Korea may apply import diversification strategies for reasons of security of supply. This may also explain the slightly higher prices in the real market, since these economies would usually pay a premium for their import diversification. Second, calorific values are indeed the most important quality parameter and are accounted for in the analysis. However, the chemical composition of coals in regard to ash and sulphur content, moisture and volatile matter may be important efficiency determinants for power plants. Some power plants may be adjusted to a specific coal type or certain types of coal from different regions are often blended to optimise coal quality at the import terminal. Third, long-term bilateral contracts are still quite common in international coal trade. Finally, statistical errors and differences in energy-mass conversion may cause differences in statistics of traded volumes.

Table 6: Comparison of actual and simulated trade flows in million tonnes (energy adjusted)

	South Africa	*Russia*	*Venezuela*	*Vietnam*	*Indonesia*	*Colombia*	*China*	*USA*	*Australia*	*Poland*	*Norway*
Actual 2006											
Europe	56	59	2	1	17	28	3	6	3	8	2
North America		2	5		3	26			6		
Latin America	2		1		2	3			1		
China		1		22	14		1		8		
Taiwan		2			29		16		13		
Japan		9		3	23		16		60		
Korea		3		1	20		17		20		
India	3				17		5		2		
South East Asia	1	2			24		2				
Total	*62*	*78*	*8*	*27*	*149*	*58*	*60*	*6*	*113*	*8*	*2*
Perfect competition 2006											
Europe	69	58			6	31		13		8	2
North America			9			28			5		
Latin America									9		
China				27	18						
Taiwan					61						
Japan		13			13				89		
Korea					1		62				
India					26						
South East Asia					30						
Total	*69*	*71*	*9*	*27*	*154*	*59*	*62*	*13*	*103*	*8*	*2*
Cournot oligopoly with fringe 2006											
Europe	17	61	2		20	17	11	19	16	8	2
North America	6		6		7	7	4		7		
Latin America	2		1		2	1	1		2		
China	6			1	10	5	7		8		
Taiwan	8			9	12	6	8		10		
Japan	13	15		9	20	11	15		17		
Korea	8			5	13	7	10		11		
India	4			1	6	3	3		5		
South East Asia	4			3	7	3	4		5		
Total	*68*	*76*	*8*	*27*	*95*	*59*	*62*	*19*	*81*	*8*	*2*

	Actual	Perfect Competition	Cournot oligopoly with fringe
Total seaborne trade	571	577	506

Source: IEA Coal Information, own calculations.

Although, the oligopolistic trade pattern differs substantially from the actual trade flows, it features a higher degree of diversification. This diversification of exports stems from the oligopolists' profit maximisation: A Cournot player exports to a certain market until marginal revenue equals marginal costs there. With a high market share in a certain importing region perceived marginal revenue for the exporter is low thus making it profitable to diversify the export structure. This may justify trade with regions that would cost-wise not occur in a perfectly competitive market.

Especially, major players in the pacific basin like Australia, Indonesia and China have a diversified supply structure in reality. Competitive behaviour would suggest that China ships all of its exports to Korea whereas in the actual market China trades the bulk of its exports with three Asian economies: Japan, Taiwan and Korea. Although, Indonesia's supply structure is more diversified by nature due to its high production, the cost-minimal solution would imply that Taiwan procures all of its imports from Indonesia. Although Taiwan is a major importer of Indonesian coal it sources its imports from several exporters. In the non-competitive market structure setup even high-cost fringe producers like the U.S. or Russia increase their market share. Since oligopolistic players withhold exports, prices rise and the fringe can capture rents by expanding its supply.

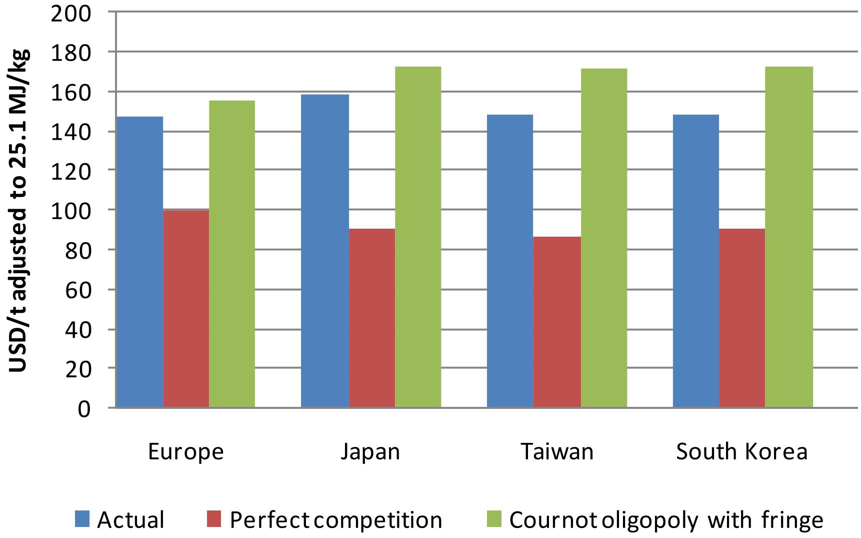
The results for 2006 reveal a relatively high degree of competition particularly in the Atlantic market. In the Pacific market we note that prices exceed marginal costs of delivery and that the actual trade pattern is more diversified than the competitive one. Clearly, the market outcome is not fully efficient from a welfare perspective suggesting that some non-competitive mechanisms applied. Further, we reject our non-competitive oligopoly with competitive fringe scenario. In this setup too much quantity is withheld and consequently prices are too high compared to actual data. However, in reality diversified export structures of major Pacific suppliers are observable. Since diversification also occurs in the Cournot scenario this may be interpreted as an indication for strategic behaviour.

Haftendorn and Holz (2010) also find that prices deviate from marginal costs and real market trade flows are more diversified than in the competitive scenario. Our results are consistent with their conclusion that steam coal trade is better characterised by perfect competition than by a non-cooperative Cournot game in 2006.

6.2 Simulation results for the year 2008

Analysing the seaborne steam coal market in 2008 reveals a different picture. In 2008 steam coal import prices soared to very high levels of more than 140 USD/t on average in the core demand regions (see figure 3). Clearly, by comparing competitive (marginal cost based) prices of 2006 (see figure 2) with corresponding prices of 2008 (see figure 3), we see that marginal costs of supply increased significantly between 2006 and 2008, too. However, the cost increment is not high enough to cause price spikes as those seen in 2008. For example, import prices in Europe were 147 USD/t, while simulated marginal cost prices (including seaborne freight rates) are 100 USD/t. Consequently, the remaining spread of 47 USD/t between marginal costs and actual prices is too large to justify perfectly competitive conduct on the seaborne trade market in this year. However, we can also reject the hypothesis of the Cournot-Nash oligopoly with competitive fringe in this market from a price perspective. Oligopolistic mark-ups are too high and prices in the Cournot setup again exceed actual prices substantially.

Figure 3: Comparison of actual and simulated prices in 2008



Source: own calculations/MCIS-steam coal marker prices

With regard to trade patterns we observe that (as in 2006) certain competitive mechanisms seem to apply (see table 7). Trade relations in the Atlantic market are quite accurately simulated in the competitive setup. The Colombian and the Russian export structures, both major suppliers for Europe, are still well approximated by the competitive model. However, the role of South Africa clearly changed. While South African exporters shipped 90% of their production to Europe this share has decreased to less than 70% in 2008. This shift of exports to the Pacific basin is not efficient. The competitive scenario shows that from a cost minimisation perspective South African coals should be directed to the European market. Thus, in the real market South African exporters could accrue higher rents in the Pacific basin indicating that prices were inefficiently high in Asian import regions.

Further, U.S. exports to Europe deviate significantly with the U.S. supplying about 15 mt more than in reality. The reason for this result may be the neglect of the U.S. domestic coal market in the model. Some of the export mining capacity attributed to the U.S. in the model normally serves the domestic market but generally has access to export infrastructure and the necessary coal quality to trade its product on the maritime market. However, exports depend not only on prices in the international market but also on domestic prices and contractual obligations. These issues can only be addressed by explicitly modelling the domestic markets.

Table 7: Comparison of actual and simulated trade flows in million tonnes (energy adjusted)

	South Africa	*Russia*	*Venezuela*	*Vietnam*	*Indonesia*	*Colombia*	*China*	*USA*	*Australia*	*Poland*	*Norway*
Actual trade flows 2008											
Europe	44	64	3	1	14	32	2	15	2	3	3
North America	1		2		2	31			1		
Latin America	2	1	1		1	8		1	1		
China		1		19	25				1		
Taiwan		1			29		11		19		
Japan	1	11		2	27		11		67		
Korea	1	9		1	26		16		19		
India	12				22		1		1		
South East Asia	2				26	2	1		5		
Total	*64*	*87*	*6*	*23*	*172*	*73*	*42*	*16*	*116*	*3*	*3*
Perfect competition 2008											
Europe	72	69				25		31		5	4
North America			5			37					
Latin America			4			12			2		
China				22	29						
Taiwan					67						
Japan									133		
Korea		19			17		45				
India					38						
South East Asia					41						
Total	*72*	*88*	*8*	*22*	*192*	*74*	*45*	*31*	*135*	*5*	*4*
Cournot oligopoly with fringe 2008											
Europe	20	69			31	24	3		28	5	
North America	4		5		7	6	2	5	7		
Latin America	2		3		3	2			3		
China	6			5	11	5	5		10		
Taiwan	7			13	13	7	6		11		
Japan	13	5			23	13	12	26	22		
Korea	9	13			15	8	9		14		
India	5				8	4	3		7		4
South East Asia	5			4	9	4	4		8		
Total	*72*	*88*	*9*	*22*	*119*	*74*	*45*	*31*	*109*	*5*	*4*
		Actual			Perfect Competition			Cournot oligopoly with fringe			
Total seaborne trade		606			677			577			

Source: IEA Coal Information, own calculations.

Simulated trade flows are again more distorted in the Pacific market. In reality the three major players in the Asian market Australia, Indonesia and China decide on a trade pattern that deviates significantly from the welfare efficient solution. Although the trade pattern of 2006 already suggested this, the effects are more pronounced in 2008. In the light of competitive prices that are considerably lower than actual prices, the hypothesis of perfect competition on the seaborne market is highly arguable in 2008.

Moreover, in 2008 the efficient equilibrium quantity of 677 mt was not supplied. Instead, total trade volume stood at 606 mt implying that not all available supply capacity was in operation. There are in fact a number of possibilities why export capacity may have been scarce during 2008.[32] Although such short-run bottlenecks are hard to quantify it seems unlikely that they

[32] The national market in the USA may have had an impact on exports due to contractual obligations or high demand. U.S. exports remained under their nominal capacity potential. Secondly, some export collieries may not

add up to more than 70 mt. Yet, steam coal allocation also does not appear to be non-competitive in terms of the selected non-competitive setup of Cournot behaviour. As in 2006, the diversified supply structure in the Cournot setup has some appeal, but total traded volumes are again too low and simulated prices too high.

7. Conclusions

In this paper we analysed the allocation and pricing of steam coal in the seaborne trade market. We demonstrated that competitive models are not able to fully reproduce real market equilibria especially in 2008. Although some competitive mechanisms seem to have applied particularly in the Atlantic region, seaborne steam coal trade is not fully efficient from a welfare perspective. Market inefficiencies are more pronounced in 2008 especially in the Pacific region, indicating that competition may have been relaxed in this market in recent years. Our results for the year 2006 are qualitatively consistent with Haftendorn and Holz (2010) who also find deviations from the competitive solution. They conclude that the market is generally competitive and suggest that deviations are due to spatial price discrimination or the pricing-in of capacity constraints. However, prices increased significantly after 2006 and remained relatively high. Since then, the market behaviour of several major Pacific players may have changed. It is therefore important to investigate a year with high prices and look at total market volume. By analysing the year 2008 we draw a different conclusion. Our results show that the spread between marginal costs and prices increased in the analysed period and capacity utilisation decreased. Supply capacity analyses by Kopal (2007), Rademacher (2008) and Bayer et al. (2009) demonstrate that substantial capacity expansion projects came on-line in 2007 and 2008. According to our analysis, total (nominal) supply capacity would have been sufficient to serve demand in 2008 without rationing.[33] Thus, we cannot reject the hypothesis of non-competitive conduct.

Yet, the results of our oligopoly setup with major suppliers competing in quantities and facing a price-taking fringe do not present evidence for such a market structure to prevail in reality.

have reached full production capacity due to strikes and bad weather conditions (see Ritschel, 2009 and Xstrata Annual Report, 2008). Thirdly, interactions between the thermal coal market and the coking coal market may have had an impact. As a small proportion of a specific steam coal quality may also be upgraded to low quality metallurgical coal by washing. The boom on global steel markets in 2008 may have forced some steel mills to use coals which would otherwise have served as thermal coal.

[33] Short term supply bottlenecks may have been responsible for the low utilisation of (nominal) capacity to some degree and may have contributed to the high prices. However, to our best knowledge there is so far no quantitative evidence to what extend such bottlenecks occurred in 2008 and it is unlikely that short term constraints have persisted over several years.

Anyhow, the export patterns of oligopolistic players in this scenario demonstrate that Cournot behaviour may generally be an explanation for the diversified steam coal allocation in reality.

In the context of the structural changes, the importance of coal in energy supply and the inability of competitive models to reproduce recent market equilibria, further research on steam coal market economics may be interesting. We suggest that future research focuses on other non-competitive pricing strategies such as spatial price discrimination and limit pricing or the role of domestic markets in international trade.

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