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818

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Berlin, September 2008

IMPRESSUM

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Fax +49 (30) 897 89-200
http://www.diw.de

ISSN print edition 1433-0210
ISSN electronic edition 1619-4535

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Analysis of the World Market for Steam Coal Using a Complementarity Model*

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September 25, 2008

Abstract

With its resource availability and the prospect of climate friendly technology, coal continues to play an important role in the global energy sector. We develop a complementarity model of the international market for steam coal. We want to analyze the level of competition in this market which is strategic for the importers' security of energy supply. In a spatial equilibrium framework, we assume the steam coal exporters to maximize their profits by choosing the optimal quantity to sell to each importing country. We compare two possible scenarios: perfect competition and Cournot competition. The results, especially the price levels, indicate that the Cournot model is not realistic, suggesting that the producing countries do not exert market power. However, the trade flows and prices observed in reality suggests that there is some form of market power with price discrimination, possibly following a Bertrand model in a spatial setting.

Keywords: coal, energy, market structure, simulation model

JEL Codes: L11, L72, C69

*This paper results from the research program "Resource Management" that is carried out jointly by DIW Berlin and Dresden University of Technology. We would like to thank Christian von Hirschhausen, Steven Gabriel, Ruud Egging, Stefan Endres, and the participants at the 2008 ENERDAY conference in Dresden and at the 2008 International IAEE conference in Istanbul for their helpful comments and suggestions. The usual disclaimer applies.

1 Introduction

The structure of international coal markets, and supply security issues related thereto, have been subject to little analysis recently, despite the increased importance of coal as a primary energy source. In fact, amid concerns about global warming and CO_2 emission reductions, coal is currently experiencing a "Renaissance" due to its relative low price and tensions on other primary energy markets (oil, natural gas). Power production based on steam coal input[1] has received increasing attention lately due to the advent of "clean-coal" technologies. These technologies, which aim at significantly reducing the greenhouse gas emissions, may considerably extend the viability of coal-based electricity generation despite the present climate change concerns. Technological advances like carbon sequestration and storage will be necessary if the dirtiest fossil fuel in traditional combustion (compared to oil and natural gas) is to be used in a medium- and long-term future.

Globally, the use of coal has considerably increased in the last years, mainly due to the high energy demand growth in China and India [12]. Most large coal consumers satisfy a significant share of their demand on the world market, often because domestic reserves have declined but left behind a certain industry structure "locked in" with coal use (e.g., in Germany, the UK). For these consumers imported steam coal became more attractive than exploiting their own high cost reserves. The world coal markets in the last decades have provided a relatively cheap supply which also attracted new consumers like China and more recently India.

Table 1 reports the import share of total consumption for the major consumers of steam coal. Several European countries rely for about 70% of their steam coal consumption on imports, for some resource-poor Asian countries (Japan, Taiwan, South Korea) this rate goes up to 100%. Table 1 also shows the contribution of imported steam coal to the total electricity generation. In the European countries this share ranges from 15% to 20 % and in Asia, is even higher ranging from 20% to more than 50% for Taiwan. China's share is lower but given the very important amount of coal used the imported steam coal is a very substantial amount in absolute terms. Given the importance of the international market for steam coal, we would like to better understand its supply structure.

Virtually all major exporters can be considered as "safe" countries in geopolitical terms and, unlike in the oil and gas markets, no sudden supply disruption on political grounds can reasonably be expected.[2] Short term supply disruptions may occur

[1]Hard coal must be distinguished into steam (thermal) and coking (metallurgic) coal, depending on its calorific content and other chemical properties. Steam coal, that is almost exclusively used for electricity production, can be considered a homogeneous good.

[2]Major exporters are Australia, South Africa, Indonesia, USA, Russia, China and Colombia.

	Import dependency rate	% of imported steam coal in electricity production
Japan	99.50%	24.38%
South Korea	95.40%	33.49%
Taiwan	100%	52.80%
UK	63.40%	21.37%
Germany	69.20%	14.26%
USA	1.80%	0.86%
China	11%	8.62%
Spain	71%	16.69%
Italy	99.50%	14.33%

Table 1: Share of imports in total consumption and share of imported steam coal in total electricity generation of major steam coal consuming countries 2006 (Source: IEA [12] and IEA [13])

due to natural disasters like storms and floods or social tensions leading to strikes. However, efficient supply management with bunkering and supply diversification can reduce the risk of disruption for the importers. While there does not seem to be a risk to security of supply with coal, we would like to investigate whether the few exporters on the world market are able to exert market power vis-à-vis their customers, many of whom with a large import dependency. In fact, it is not clear whether the recent price spike (with prices raising by more than 65% between 2003 and 2007) is due to a demand shift only, or whether the market structure has become more oligopolistic. To address this issue, we develop a static numerical simulation model, COALMOD, and will use scenario analysis to compare different supply structures with the real market outcome of today's (2005 and 2006) market. The model covers seaborne international trade of steam coal which is the type of coal used for electricity generation.

Recent research of international coal markets has pointed out that the traditional separation of the Pacific and the Atlantic market has faded (e.g., Ellerman [5], Warell [21] and Li [16]). We will therefore consider the global market as one integrated market, albeit not neglecting the spatial aspect of the market where transport costs play a role in determining the trade relations. We also consider steam coal to be a homogenous product using the IEA [12] definition of a gross calorific value of more than 5700 kcal/kg.

In the remainder of the paper, we first give an overview over the literature of coal market and spatial equilibrium modeling. We then describe the COALMOD model by its mathematical structure and data input. The subsequent presentation of our model results shows that both, the competitive and the Cournot market model, have some explanatory power of the 2005 and 2006 trade patterns. In particular, the results suggest that price discrimination in a spatial framework takes place. In the concluding section we discuss several model extensions to be explored.

2 State of the literature

The modeling effort applied to international steam coal trade has been rather sparse in the last decade in particular when compared to other energy commodity markets like natural gas. Often, coal trade is embedded in energy system models. For example, Golombek el al. [7] investigate the impact of energy market liberalisation and climate policy on coal transport demand in Western Europe and Japan with a numerical equilibrium model (LIBEMOD) [1]. While it is primarily a model of the West European natural gas and electricity markets, it also includes the West European and the world market for coal. This model assumes perfect competition on the coal market.

Another example is the International Component of the Coal Distribution Submodule (CDS-IC) which is part of the Coal Market Module (CMM) [4] of the U.S. National Energy Modeling System (NEMS). The CDS-IC is used as an input for the NEMS in order to forecast US coal imports but is also an international trade model. The world coal trade is modeled using linear programming minimizing costs. The assumed trade pattern thus is perfect competition with constraints of diversification for the importing countries and for the producers.

A modeling approach that has been widely used to study international commodity trade is spatial equilibrium modeling. One of the earliest models of this type was formulated by Samuelson [19]. Starting from the question of pricing in spatially separated markets, Samuelson developed a linear programming model maximizing the net social pay-off in order to find an equilibrium in perfectly competitive markets. This problem was reformulated by Takayama and Judge [20]. They present a quadratic programming formulation and an algorithm that solves Samuelson's partial equilibrium formulation and extend it to a multi-commodity set.

But perfect competition models often delivered disappointing results as trade flows and prices did not reflect the reality. This was also the case for the international steam coal market in the early 1980's and motivated Kolstad and Abbey to model imperfect competition [14]. Their model is one of the few that specifically represents international steam coal trade. They examine whether market power excerted by some players could be responsible for the observed trade patterns. The players are exporting and importing countries and Kolstad and Abbey explore four different market scenarios: perfect competition, monopoly, Cournot-Nash duopoly and duopoly/monopsony with a competitive fringe. They conclude that a supply duopoly (South Africa and Australia) and an import monopsony (Japan) is very similar to the actual trade pattern of the 1980s.

The situation on the international steam coal market has evolved since then and it is the goal of our paper to understand which market conduct influences today's trade patterns. Given the spatial character of the market and our earlier expertise on Cournot modeling of natural gas market (e.g. Holz et al. [10] and Egging et al. [3]) we concentrate on a spatial Cournot model. A general formulation of how the Takayama-Judge spatial equilibrium model can collapse into a spatial Cournot model can be found in the paper by Yang, Hwang and Sohng [22]. Their spatial equilibrium Cournot model was be solved using linear complementarity programming and is applied to the US coal market. However, the results of the spatial Cournot model are not satisfying compared to the observed trade pattern and in the case of the US coal market, the competitive spatial equilibrium model yields better results.

3 The COALMOD Model

3.1 Description of the Analytical Model

Our model, called COALMOD, follows the literature of energy sector complementarity models. The international steam coal market is modeled as a non-cooperative static game between the suppliers (exporters). The exporters are assumed to maximize their individual payoffs (profits). The exporters produce the steam coal, sell it and transport it to the importers. Importers are characterized by a demand function for imported steam coal. The market can be simulated as a Cournot model with the possibility for the export countries to exert market power or as a perfect competition model where the exporters are price takers.

The exporters l maximize their profit $\Pi_{lc}(y_{lc})$, defined by the revenue net of costs of production and transport to each importing country c by choosing the optimal quantity y_{lc} to sell to each importing country c, given a production and an export capacity constraint. Thus, the trade flows y_{lc} and the associated prices p_c in the importing country c are endogenous model results. Exogenous data inputs are the parameters of the demand functions, production costs, transport costs and the production and export capacity constraints for each exporting country. In particular, we chose a linear demand function defined around a reference point, a quadratic production cost function and an affine transport cost function (see 3.2 for details and the parameter input), but other specifications are possible.

For a linear demand function of the type $p_c = a_c + b_c y_c$, a strategic player l

with the capacity to influence the demand function has the following optimization problem of exports to importer c:

$$\max_{y_{lc}} \Pi_l(y_{lc}) = \sum_c p_c\left(\sum_l y_{lc}\right) \cdot y_{lc} - c_l\left(\sum_c y_{lc}\right) - \sum_c trans\_c_{lc} \cdot y_{lc} \tag{1}$$

s.t. production and export capacity of country l are respected and the decision variable is non-negative:

$$prod\_cap_l - \sum_c y_{lc} \geq 0 \quad (\lambda_l) \tag{2}$$

$$exp\_cap_l - \sum_c y_{lc} \geq 0 \quad (\mu_l) \tag{3}$$

$$y_{lc} \geq 0 \tag{4}$$

We chose the functional forms of the profit function (demand and cost functions) such that the first-order conditions (also known as Karush-Kuhn-Tucker conditions, KKT) of the optimization problem are necessary conditions for the optimal solution (see section 3.2 for the functions). Taking the KKTs of all players l simultaneously will give a non-linear complementarity problem. We obtain the following Karush-Kuhn-Tucker (KKT) conditions of the optimization problem (1) - (4):[3]

$$0 \leq -p_c - b_c \cdot y_{lc} + \frac{\partial c_l}{\partial y_{lc}} + \frac{\partial trans\_c_l}{\partial y_{lc}} + \lambda_l + \mu_l \qquad \perp y_{lc} \geq 0 \tag{5}$$

$$0 \leq prod\_cap_l - \sum_c y_{lc} \qquad \perp \lambda_l \geq 0 \tag{6}$$

$$0 \leq exp\_cap_l - \sum_c y_{lc} \qquad \perp \mu_l \geq 0 \tag{7}$$

We consider a strategic player that takes into account his influence on the demand function and whose derivative of the demand function is $\frac{\partial p_c(y_c)}{\partial y_{lc}} = b_c$. The term $b_c \cdot y_{lc}$ gives the oligopolistic mark-up that the strategic player can obtain. A competitive player, on the other hand, does not take into account the demand function but behaves as price taker. For such a player $\frac{\partial p_c}{\partial y_{lc}} = 0$. We can therefore introduce a market power parameter α_l for each player l that is multiplied with the term $b_c \cdot y_{lc}$ and that is defined as $\alpha_l = 0$ for a competitive player l, and $\alpha_l = 1$ for a Cournot player. Indeed, α_l is nothing else than the standard conjectural variation definition

[3]Following the standard literature, the profit maximization problem is turned into a minimization problem before deriving the KKTs. The FOCs of a minimization and a maximization problem differ only by their signs, but the non-negativity constraint of all dual variables is kept valid only for the minimization problem.

of a competitive (price-taking) and Cournot player l reacting to their competitors $-l$.

Combining the KKT conditions (5) - (7) with a market clearing condition for the import market, we will obtain a unique equilibrium solution for the market model. The following market clearing condition determines the price given the demand function $p_c(y_c)$.

$$p_c - p_c\left(\sum_l y_{lc}\right) = 0, \quad p_c \quad \text{(free)} \tag{8}$$

This complementarity model is programmed in GAMS, and solved with a standard algorithm for MCP (mixed complementarity problems), PATH.[4]

3.2 Data

This section details the parameter input for the model described above. We use data for exports and imports at the country level, and assume each country to be one player.[5] Table 2 details the countries used in the data set, which are the main exporters and importers on the international steam coal market.[6]

Exporting Countries	Importing Countries
Australia	Japan
Indonesia	Taiwan
South Africa	South Korea
Russia West (Baltic Sea)	United Kingdom
Russia East (Pacific)	Germany
China	United States of America
Colombia	Spain
United States of America	Italy
	India
	China

Table 2: Countries in the COALMOD Model

[4] Cf. Ferris and Munson [6] for an overview.

[5] In the case of Russia, due to its large geographic extension, we assume two players, one on the Western (Baltic) shore and one on the Eastern (Pacific) shore. One could argue that a similar split-up would be appropriate for the US. However, given that the largest coal import terminal is Mobile (Alabama), a port on the Gulf coast which is centrally located, we chose to include a single US importer which can be reached from both basins.

[6] China and the United States of America are both, exporting and importing countries. Hence they are introduced twice, as exporting and as importing country. In order to keep the model consistent, the exporter and importer of the same country are not allowed to trade with each other. This is because we focus on the international trade and do not aim at a representation of domestic markets.

As mentioned in Section 3.1, we assume a linear inverse demand funtion of the type $p_c = a_c + b_c y_c$ for each importer c. We construct a different linear inverse demand function for each importing country c using their reference prices (p_c^{ref}) and reference quantitities ($y_c^{ref} = \sum_l y_{lc}^{ref}$) of each base year 2005 and 2006 and assumptions on the demand elasticities (ε_c). In particular, we define $b_c = \frac{p_c^{ref}}{y_c^{ref}} \cdot \frac{1}{\varepsilon_c}$ and $a_c = p_c^{ref} - b_c \cdot y_c^{ref}$, following the demand elasticity definition $\varepsilon_c = \frac{y_c - y_c^{ref}}{p_c - p_c^{ref}} \cdot \frac{p_c}{y_c}$ This gives the following inverse demand function:

$$p_c = p_c^{ref} + \frac{1}{\varepsilon_c} p_c^{ref} \left(\frac{\sum_l y_{lc}}{y_c^{ref}} - 1 \right) \tag{9}$$

The reference import quantities and CIF (cost insurance freight) prices for the years 2005 and 2006 are obtained from the OECD's International Energy Agency [12]. Demand elasticities ε_c are chosen during the calibration process and based on [17]. In the benchmark specification we use $\varepsilon_c = -1/3$ for all countries.

The production cost function of each exporter is assumed to be quadratic of the type $c_l = (ac_l + bc_l \cdot Y_l) \cdot Y_l$, with total production $Y_l = \sum_c y_{lc}$. Thus the marginal cost function is $mc_l = ac_l + 2 \cdot bc_l \cdot Y_l$. The cost functions are obtained using data provided by RWE [18] that gives lower and upper bounds on average costs for each exporter. This information is used to construct linear average cost curves. The intercept parameter ac_l corresponds to the lower bound. In order to determine the slope bc_l we used a second point defined by the maximal production capacity and the upper bound of the average costs assuming a linear average cost function $avc_l = ac_l + bc_l \cdot Y_l$.

The transport cost function is assumed to be affine, with $trans\_c_{lc}(y_{lc}) = \theta_{lc} \cdot y_{lc}$, such that we have constant unit (marginal) costs θ_{lc}. The parameter θ_{lc} is derived for each importer-exporter pair lc depending on the distance between the major ports of each country. Marginal transport costs are a linear function of the distance of the form $\theta_{lc} = \kappa^{short/long} + \tau^{short/long} \cdot \text{distance}_{lc}$. The parameter values κ and τ can take two different values depending on whether the distance of lc is a long or a short distance (longer or shorter than 4500 nautical miles[7]). Specifically, for short distances, $\kappa^{short} = 2.6$ and $\tau^{short} = 0.03$, and for long distances, $\kappa^{long} = 11.98$ and $\tau^{long} = 0.0008$. Thus, we assume a large fixed cost and a flat slope for transporting over long distances, while transporting over shorter distances involves less fixed costs but is more strongly dependent on the actual distance traveled.

[7]This threshold level is approximately the distance between Colombia and the European ARA (Amsterdam-Rotterdam-Antwerp) port. It was chosen based on some selected observations of freight rates for each base year 2005 and 2006 and reported in the technical literature and [12].

Finally, data on production capacities is from Kopal [15]. This is production capacity that is available for exports (export mines). Export capacities are export harbor capacities and are based on RWE [18] and VDKI [2]. We implicitly assume that shipping (boat) and import harbor capacity is available without capacity limitation.

4 Results

In this paper, we would like to find out which market scenario is more likely to explain the trade pattern of the international steam coal market observed in 2005 and 2006. Following Kolstad and Abbey [14], we investigate the supply structure of the market. This can give us an indication of whether import dependent countries must pay a higher price than the competitive price level and are subject to the exercise of market power by the exporters.

Moreover, the model introduced above is able to indicate whether there are physical bottlenecks in the production and export capacity that hinder the coal trade. A positive value of the dual prices λ_l and μ_l of the capacity constraints (2) and (3), respectively, points to a capacity limitation for exporter l. Bottlenecks can potentially indicate in which exporting countries there is need for investment in the producing and exporting infrastructure. One possible reason why bottlenecks can occur is that the players withhold capacities in the long-run to sell low quantities and obtain high prices. Bottlenecks can also occur when the demand rises abruptly as investments to expand production and export capacities cannot be done in the short term. In 2005 and 2006 export capacities were observed to be generally sufficient. On the contrary in 2007 due to higher demand and some storm in Australia, Australian ports experienced heavy congestions.

The model is run for two different market scenarios on the supply side: perfect competition and Cournot competition. The scenarios are implemented via a modification of the value of parameter α_l. For the scenario of a perfectly competitive market, we set $\alpha_l = 0$ for all l; conversely, $\alpha_l = 1$ for all l in the Cournot scenario.

Total import quantities (Figure 1 and 2) obtained in both scenarios show a remarkable similarity of the perfect competition results with the reference data for 2005 and 2006. The Cournot scenario, on the other hand, gives smaller quantities and considerably higher prices than observed in reality.

The detailed results are presented in the Appendix. Table 4 and Table 5 show the details of the simulated trade flows between each exporter and each importer for 2005, which must be compared to Table 6 that shows the trade flows that occured in reality. For the year 2006, the Tables 8 and 9 show the simulation results and

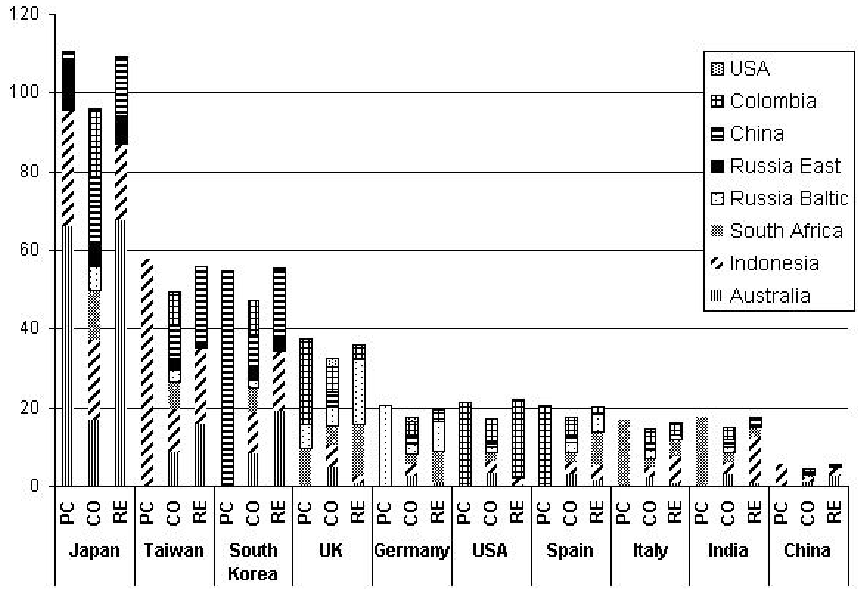

Figure 1: Imported quantities in the perfect competition (PC), Cournot scenario (CO), and reference data (RE) in 2005, in million tons (Mt)

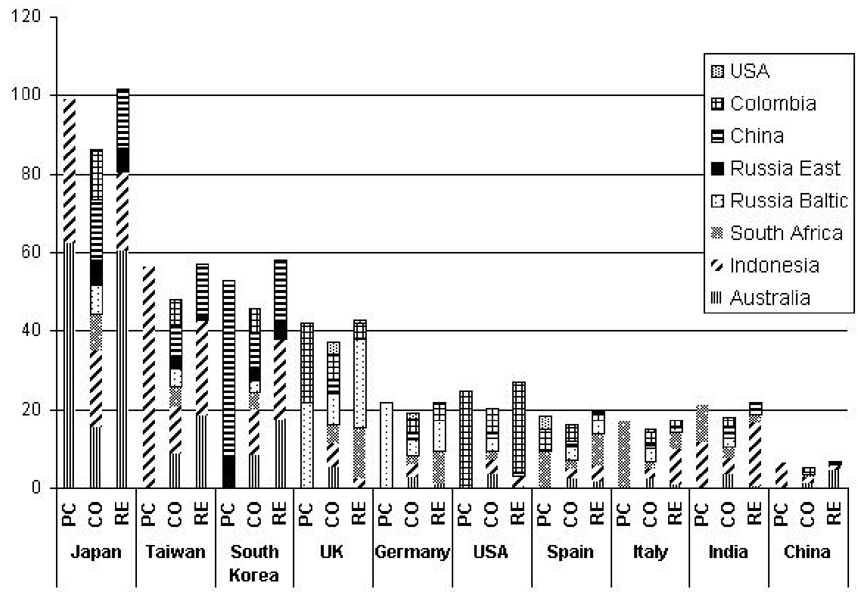

Figure 2: Imported quantities in the perfect competition (PC), Cournot scenario (CO), and reference data (RE) in 2006, in million tons (Mt)

Table 10 the reference quantities. It is quite obvious that the number of flows (number of trading relations) in the perfect competition scenario is small and that most importing countries rely on only one or two suppliers. Real world flows in 2005 and 2006 showed significantly more diversification of imports. The Cournot results present a more extreme picture with each importer buying from virtually all exporters.

The results of the perfect competition scenarion with little diversification are

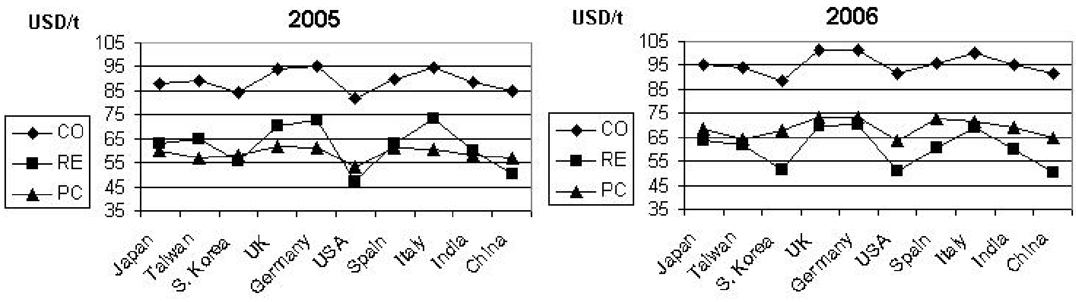

Figure 3: CIF Prices in the perfect competition (PC), Cournot scenario (CO), and reference data (RE) in 2005 and 2006, USD per t

driven by the cost-minimization mechanism that characterizes competitive markets. There is no mark-up on the marginal cost price. Each country imports from the supplier that has the lowest production and transport costs to deliver the coal to that market. In Cournot markets, on the other hand, prices are above their marginal cost levels (also see Tables 3 and 7) and these higher prices attract a larger number of suppliers, including those with higher costs.[8] Although the more diversified trade flow picture makes the Cournot scenario an attractive explanation of the real-world market, we must discard it due to the very high prices and small total quantities obtained when compared to the reference data.

Comparing the results for both years with prices shown in Figure 3, three important remarks can be made. First, the prices of the perfect competition simulation are closer or in the same range as the real observed prices. But, second, the variation of reference prices between the countries in reality is the same as in the Cournot simulation. It is important to note that the Cournot competition allows for price discrimination whereas the perfect competion simulation does not. Third, the price levels in the model results for 2006 are high, with perfect competition prices even above the real price level. This can be mainly explained by demand increases in China and India but also in the USA and Europe and a tighter supply situation due to the fact that China reduced it export licences by 10 Mt.

We also observe that the Australian exporter supplies less to the market than its potential. Different explanations apply for the perfect competition and the Cournot market case. In the perfect competition case, the marginal cost pricing mechanism leads to relatively expensive supply costs of all units given the diversity and broad cost range of Australian coal mines. With Australia supplying less than in the reference years, other exporters increase their supplies, up to reaching binding export capacities (South Africa, Russia, China and Colombia). Their μ_l value is twice as

[8]In our Cournot results, we even obtain a number of trade flows between the Atlantic and Pacific basins, including extremes like the Russian Baltic exporter supplying to the Asian market.

high in 2006 as in 2005 due to the higher demand and this partly also explains the higher prices for the perfect simulation results.

In the Cournot market, Australia, which is one of the key players in the global market and a price setter in the Pacific market, uses price discrimination and supplies at different (FOB) prices to different importers. The fact that Australia and possibly other players price discriminate is a form of market power. Seminal research by Hoover [11] and Greenhut and Greenhut [8] analyses spatial price discrimination and shows how firms use the advantage of their and their rivals' location to increase prices above marginal costs. Spatial price discrimination in the theoretical framework of Cournot and Bertrand markets was also analysed by Hobbs [9]. He finds that the introduction of space causes Bertrand prices to deviate from the marginal costs and that the degree to which firms can exercise market power and raise prices above marginal costs grows with interfirm distance. In the Bertrand model, the price "will fall to a level below the second lowest marginal costs among the firms, and the firm with the lowest marginal cost will serve" the demand. Another interesting finding of Hobbs [9] is that the prices in the Cournot model are always the highest of all models and, depending on the conditions, significantly higher than in the Bertrand spatial model. Related to our results where the prices in the Cournot competition scenario are very high compared to the real prices, this information gives precious insights in how the international steam coal market works and may be modeled better. However, no application of the spatial Bertrand model exist to our knowledge.

Physical bottlenecks in a Cournot simulation framework are an indication that players are withholding capacities in order to achieve low (Cournot) quantities and hence increase the price. But in a competive framework the players would have an incentive to remove the bottlenecks in order to maximize profits. Between 2005 and 2006 we have seen some investment activity in the market. Indonesia expanded its coal export terminals and in the model there is no more binding restiction in 2006. Russia also increased its export capacities. South Africa had technical problems in both 2005 and 2006 which affected its export capacity but is currently expanding its main coal export terminal at Richards Bay. This somewhat supports the result of a more competitive supply structure. Kopal [15] also describes that bottlenecks in the coal sector have not been lasting in the last decades and that the industry has been reactive to investment signals.

Another interesting result are the imported quantities for Japan, the largest coal importer in the global market. If we compare (see Figure 1) the repartition of the imported quantities in reality and in the perfect competition case in 2005[9] we see a

[9]We do not consider the 2006 results here as they are somewhat distorted by the demand increase and the high marginal costs of Australian supplies

very good match. This means that in reality Japan is able to import its coal in a very efficient way, buying from the most advantageous sources. This may be linked to the structure of the Japanese industry and the fact that a large number of Australian mines are partly owned by Japanese firms. The Japanese trading houses, the sogo sosha, are part of the same keiretsu conglomerates that also own Australian mine asset. These trading firms are very effective and via their mine ownership Japanese traders and customers have good insight into the mining costs.[10]

5 Conclusions

We have presented a complementarity model of the international steam coal market which we have used for numerical simulations for the years 2005 and 2006. Our aim was to find out whether this market is subject to the exercise of market power by its major players. We find evidence that rejects a Cournot market structure for the years 2005 and 2006. Our perfect competition simulation results for total exported and imported quantities are closer to the real trade volumes. This differs from the earlier paper by Kolstad and Abbey [14] who, with a similar model and a smaller data set, find that the market of the 1980s was subject to the exercise of market power by oligopolistic suppliers and a monopsonistic importer.

However, our price results suggest that a more differentiated analysis needs to be done. On the one hand, the prices in the Cournot case are well above the real-world prices and suggest that the steam coal market does not work à la Cournot. On the other hand, the variation of prices between the importing countries is considerably higher in reality than in the perfect competition case. This result indicates that there may be price discrimination which does not exist in a perfectly competitive market. The spatial Bertrand model may be the appropriate framework but needs further research.

This paper is part of the literature on spatial and complementarity equilibrium modeling commenced by Samuelson [19] and advanced by Takayama and Judge [20] and widely used for electricity and natural gas market modeling in the last two decades. As such, it represents the equilibrium solution of a chosen theoretical market structure. This implies that short-run supply disruptions, like the Australian export stop in summer 2007 due to inclement weather or the Colombian mining worker strikes in 2006, may lead to bottlenecks that are not shown by our model.

Future research should broaden the COALMOD model and deepen some aspects. In particular, it seems sensible to proceed to a more detailed representation of the

[10]Indeed, Kolstad and Abbey [14] concluded that modeling Japan as a monopsonic consumer with market power was a plausible explanation for the international coal market in the 1980s.

supply side. In fact, there are four large multi-national companies operating in virtually all coal exporting countries, sometimes called the “Big Four”: BHP-Billiton, Rio Tinto, Glencore Xstrata, and AngloAmerican. These four companies may well have oligopolistic or at least spatial market power. Distinguishing different company players in the exporting countries will improve the model results and avoid the problem of aggregate cost curves as for Australia. Besides the vertical market structure, it would also be interesting to analyze the horizontal market structure, the “Big Four” being active in a large bandwidth of mineral resource markets (coal, copper, iron ore, manganese etc). Lastly, in order to take into account the dynamics of the world coal market, e.g. developments in China, we suggest to develop a dynamic model with endogeneous investment decisions in production and export capacity and with a more detailed representation of the demand side and several demand scenarios.

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Appendix

	Cournot simulation	Perfect competition simulation	2005 CIF Prices
Japan	88.19	60.21	62.73
Taiwan	88.94	56.76	(65e)
South Korea	84.04	58.26	55.76
UK	93.95	61.65	70.24
Germany	95.03	61.42	72.48
USA	82.13	52.99	47.39
Spain	89.97	61.02	62.94
Italy	94.80	60.31	73.2
India	88.49	58.32	(60e)
China	84.83	57.01	50.39

Table 3: Simulated import prices and reference CIF prices for 2005, in USD per ton

	Japan	Taiwan	S. Korea	UK	Germany	USA	Spain	Italy	India	China
Aus.	66.06									
Indo.	29.68	57.83								5.48
R.S.A.				9.64				17.01	17.69	
Ru.W.				6.13	20.44					
Ru.E.	13.02									
China	1.84		54.81							
Col.				21.70		21.22	20.13			
USA							0.46			

Table 4: Steam coal trade flows in the 2005 perfect competition scenario, in million tons (Mt)

	Japan	Taiwan	S. Korea	UK	Germany	USA	Spain	Italy	India	China
Aus.	17.04	8.74	8.36	5.03	2.73	3.19	2.84	2.34	2.81	0.99
Indo.	19.98	10.91	10.40	5.40	2.92	3.01	3.07	2.50	3.32	1.29
R.S.A.	13.02	6.86	6.29	4.80	2.61	2.56	2.69	2.20	2.54	0.77
Ru.W.	5.67	3.24	2.10	5.05	2.75	1.41	2.62	2.16	1.29	0.30
Ru.E.	6.27	2.84	2.71	0.28	0.24			0.31	0.16	0.21
China	16.29	8.35	8.66	3.48	1.92	1.61	1.86	1.68	1.97	
Col.	17.32	8.47	8.59	6.45	3.42	5.38	3.74	2.79	2.82	0.97
USA	0.39	0.14		1.99	1.15		0.97	0.75	0.13	

Table 5: Steam coal trade flows in the 2005 Cournot scenario, in million tons (Mt)

	Japan	Taiwan	S. Korea	UK	Germany	USA	Spain	Italy	India	China
Aus.	67.38	15.82	19.21	0.93	0.77	0.07	1.43	0.68	0.84	2.45
Indo.	19.51	19.13	15.38	1.62		2.24	3.78	6.80	11.66	2.40
R.S.A.	0.05	0.34		13.03	8.22	0.07	8.74	4.40	2.36	
Ru.W.				16.83	7.50	0.36	4.24	1.08		
Ru.E.	7.16	0.75	3.02							0.84
China	15.17	19.66	17.58	0.13		0.02	0.05		2.59	
Col.				3.30	2.94	19.25	1.94	3.00		
USA			0.37	0.30	0.13		0.23	0.20	0.07	0.01

Table 6: Actual steam coal trade flows in the base year 2005, in million tons (Mt)

	Cournot simulation	Perfect competition simulation	2006 CIF prices
Japan	95.43	68.52	63.33
Taiwan	94.12	64.36	(62e)
South Korea	88.53	67.63	51.73
UK	101.34	73.57	69.91
Germany	101.34	73.30	70.12
USA	91.79	63.45	50.55
Spain	95.92	72.95	60.66
Italy	100.04	71.66	69.16
India	95.54	69.28	(60e)
China	91.31	64.67	50

Table 7: Simulated import prices and reference CIF prices for 2006, in USD per ton

	Japan	Taiwan	S. Korea	UK	Germany	USA	Spain	Italy	India	China
Aus.	62.40									
Indo.	36.65	56.20	0.01						11.48	6.21
R.S.A.							9.53	17.05	9.39	
Ru.W.				21.71	21.59					
Ru.E.			7.79							
China			45.00							
Col.				20.44		24.88	5.60			
USA							3.10			

Table 8: Steam coal trade flows in the 2006 perfect competition scenario, in million tons (Mt)

	Japan	Taiwan	S. Korea	UK	Germany	USA	Spain	Italy	India	China
Aus.	15.25	8.44	8.30	5.10	2.61	3.47	2.23	2.22	3.29	1.12
Indo.	19.63	12.01	11.73	6.32	3.23	3.58	2.87	2.71	4.40	1.66
R.S.A.	9.26	5.40	4.33	4.75	2.43	2.38	2.05	2.00	2.69	0.69
Ru.W.	7.44	4.35	3.06	7.92	4.06	3.28	3.41	3.04	2.34	0.55
Ru.E.	6.52	2.80	2.73					0.00	0.15	0.27
China	15.29	8.57	9.19	3.38	1.73	1.63	1.33	1.52	2.37	
Col.	12.64	6.44	6.40	6.79	3.47	6.00	3.09	2.60	2.66	0.83
USA	0.06			2.79	1.44		1.05	0.85	0.10	

Table 9: Steam coal trade flows in the 2006 Cournot scenario, in million tons (Mt)

	Japan	Taiwan	S. Korea	UK	Germany	USA	Spain	Italy	India	China
Aus.	60.41	18.44	17.34	0.15	0.70	0.15	1.58	0.88	0.44	4.44
Indo.	20.20	24.30	20.70	2.15		2.86	4.02	8.73	16.05	1.42
R.S.A.	0.08	0.07		13.08	8.52	0.06	8.21	4.78	2.20	
Ru.W.				22.55	8.21	0.85	3.61	0.82		
Ru.E.	6.09	1.31	3.93							0.96
China	14.77	12.74	15.65	0.03		0.04	3.00		3.21	
Col.				4.07	4.00	22.99	1.53	2.03		
USA			0.54	0.79	0.47		0.45			

Table 10: Actual steam coal trade flows in the base year 2006, in million tons (Mt)