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Oligopolistic Supply in Coal Markets?
Modeling the International Steam Coal Trade

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Oligopolistic Supply in Coal Markets? Modeling the International Steam Coal Trade

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Abstract

Coal continues to play an important role in the global energy sector and with an increase in international trade a global market for steam coal has developed. We investigate market structure and recent price developments with a numerical modeling approach and develop two partial equilibrium models. One model treats coal as a homogeneous good where quantities expressed in tons are consumed and supplied. The other model uses both tonnages and energy values and defines a different coal quality for each supplying country. 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 investigate the market structure by comparing two possible scenarios for the years 2005 and 2006: perfect competition and Cournot competition. The first result of this report is that, for both models, the simulation of perfect competition better fits the observed real market flows and prices. However it is not a complete explanation of reality and we show that time lags in the pricing-in of capacity constraints are additional mechanisms in the market. In addition to the market structure analysis, we perform a number of scenario runs, in order to assess the vulnerability of the coal importers to some specific events. We find that the European importers are generally affected less than the Asian importers when less coal is available on the world market. They can benefit from a number of substitution possibilities, both from the Atlantic and the Pacific basin.

Keywords: coal, energy, market structure, simulation model

JEL Codes: L11, L72, C69

*This report results from a cooperation with Clemens Haftendorn and Franziska Holz (both DIW Berlin).

1 Introduction

This deliverable studies whether the European importers of steam coal are subject to the exercise of market power by the suppliers and quantifies the effect of some possible disruption scenarios. Given the relatively diversified supply structure, discussed in Deliverable 5.3.3, only monopolistic or oligopolistic market power could present a risk to reasonably priced imports and must be investigated. The chosen scenarios are specific to the possible risks in the coal market, and we also use a dataset with the detail needed to investigate the international coal trade. We do not base ourselves on the POLES model data set because it has very little detail on international coal markets (only three world regions in the coal market, as opposed to our disaggregation by country). We also do not use the POLES results for our data set because they were finalized much later than our model setup. Combining the POLES scenarios with a detailed coal market model remains an interesting and challenging task for the future.

Given the multitude of steam coal exporters in the world market[1], the existence of one monopolistic suppliers can be doubted; Rademacher (2008) showed that a monopolistic cartel market structure is also unlikely. Hence, we concentrate on analyzing whether oligopolistic steam coal exporters can extract consumer rents from the importer, thereby reducing the importers' welfare and creating the risk of capacity shortage. In our modeling approach, we consider the Cournot oligopoly model, but we extend our analysis further to include temporal considerations. Overall, however, the market is rather competititively organized which is also confirmed by the dynamic investment reactions in supply capacities following the price increases since 2006.

This report analyses the trade flows and prices on the international market for steam coal[2] by simulating the market for the years 2005 and 2006 using the complementarity modeling technique. We develop two models: first, a trade model which is quantity-based and thus treats steam coal as a homogeneous good. Second, a model that is extended to include energy values and accounts for the energy contents of different coal qualities. Both models can simulate a competitive market game or an oligopolistic market game with imperfect competition à la Cournot. The model also includes capacity restrictions for production and export activities. The main result of this report is that for both models the simulation of perfect competition better fits the observed real market flows and prices in 2005 and 2006. We find, however, that using both energy and quantity values is necessary to appropriately model coal markets. Using the models, insights are provided on the pricing strategies in a spatial market with production and export capacity restrictions.

Recent research of international coal markets has pointed out that the traditional

[1] The major exporters are Australia, South Africa, Indonesia, Russia, China, Colombia and the USA.

[2] Hard coal must be distinguished into steam (thermal) and coking (metallurgic) coal, depending on its calorific value and use. Steam coal, the subject of this analysis is almost exclusively used for electricity production.

separation of the Pacific and the Atlantic market has faded (e.g., Ellerman, 1995; Warell, 2006; Li, 2008). In our modeling effort 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. Simultaneously to the trend of global market integration, we also observe a trend towards commoditization of coal in increasingly liquid market places. This means that coal is traded more and more as a homogeneous good which is reflected by the the creation of price indexes with standardized coal qualities and an increasing volume of paper trade. The trend toward commoditization is a motivation to use a quantity-based model of the steam coal trade.

However, the energy content of steam coal sold on the international market varies depending on the producer. The differences in coal qualities on the international market are not as large as between the coal types that are produced and sold domestically[3] but there are still some significant variations. This gives the motivation to additionally implement a model that incorporates different coal qualities and uses both types of information, about quantity and energy. We can then compare its results to the outcome of the quantity based model. Previous modeling work also used energy values as we discuss in the following literature review.

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, the LIBEMOD model (Aune et al., 2004) is primarily a model of the West European natural gas and electricity markets, but it also includes the West European and the world market for coal. This model only deals with energy values and assumes perfect competition on the coal market.

Another example is the Coal Market Module (EIA, 2007) of the U.S. National Energy Modeling System (NEMS). It is an international trade model that produces a forecast of US coal imports for the NEMS. The model incorporates both quantity and quality information and the world coal trade is modeled using linear programming minimizing costs for a fixed demand. The assumed trade pattern is perfect competition with various externally imposed constraints like import diversification and quality constraints. Hence the economic foundation of this model is relatively weak.

A modeling approach that has been widely used to study international commodity trade is spatial equilibrium modeling, first initiated by Samuelson (1952). Starting from the question of pricing in spatially separated markets, Samuelson developed a linear programming model maximizing welfare to find an equilibrium in perfectly competitive mar-

[3]Typically, low quality coal such as lignite is sold domestically. The relatively low energy content per ton compared to steam coal makes the long-distance transport uneconomic.

kets. This problem was reformulated by Takayama and Judge (1964). 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 modeled 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 (1984) to model imperfect competition. Their model (described in Kolstad et al., 1983) is one of the few that specifically represents international steam coal trade and also uses quantity and energy values. However, the model does not incorporate any capacity restriction which can significantly influence model outcomes. Kolstad and Abbey (1984) examine whether market power exerted by some players could be responsible for the observed trade patterns. 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.

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 et al. (2002). Their spatial equilibrium Cournot model is solved using linear complementarity programming and is applied to the US coal market. This model uses energy values and the results of the spatial Cournot model are compared to the observed trade pattern. In the case of the US coal market, the competitive spatial equilibrium model yields better results.

The situation on the international steam coal market has evolved since the 1980s and it is the goal of our analysis to understand which market conduct influences today's trade patterns. Given the spatial character of the market and our earlier experience with Cournot modeling of natural gas markets (e.g., Holz et al., 2008; Egging et al., 2008) we concentrate on a partial equilibrium Cournot model in a spatial setting.

3 The COALMOD Model

3.1 Description of the analytical model

We adopt a complementarity approach which is regularly used in energy sector modeling. 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 x maximize their profit $\Pi_{xm}(y_{xm})$, defined by the revenue net of costs of production and of transport to each importing country m by choosing the optimal trade flow y_{xm} to sell to each importing country m, given a production and an export capacity constraint. Thus, the trade flows y_{xm} and the associated prices p_m in the importing

	CMT Model	CMT-E Model
Demand	Million tons	Petajoules
Prices (p_c)	USD/ton	USD/Gigajoule
Trade flows (y_{lc})	Million tons	Petajoules
Production costs	USD/ton	
Transport costs	USD/ton	
Production capacities	Million tons	
Export capacities	Million tons	

Table 1: Units used for the COALMOD-Trade and COALMOD-Trade-Energy models

country m 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. We chose a linear demand function defined around a reference point, a quadratic production cost function and use unit transport costs (see 3.2 for details and the parameter input).

We specify two models that differ in the units assigned to the parameters and variables described above (see Table 1). In the following, we will abbreviate the specification that relies only on mass quantities with "COALMOD-Trade"(CMT) and the specification that also includes the energy content of the coals with "COALMOD-Trade-Energy"(CMT-E). For the energy specification of the model we use a conversion factor κ_x expressed in tons per Gigajoules. This factor defines a quality of coal supplied by the exporter x and is employed to express costs and capacities per energy value. The following equations describe the energy specification of the model, in which the conversion factor κ_x is added. The model structure for the quantities-only specification is the same without the energy conversion factor and can be found in detail in Haftendorn and Holz (2008).

For a linear demand function of the type $p_m = a_m + b_m y_m$, a strategic player x with the capacity to influence the demand function has the following optimization problem of exports to importer m:

$$\max_{y_{xm}} \Pi_x(y_{xm}) = \sum_m p_m \left(\sum_x y_{xm} \right) \cdot y_{xm} - c_x \left(\sum_m \kappa_x \cdot y_{xm} \right) - \sum_m trans\_c_{xm} \cdot \kappa_x \cdot y_{xm} \quad (1)$$

such that production and export capacity of country x are respected and the decision variable is non-negative:

$$prod\_cap_x - \sum_m \kappa_x \cdot y_{xm} \geq 0 \quad (\lambda_x) \quad (2)$$

$$exp\_cap_x - \sum_m \kappa_x \cdot y_{xm} \geq 0 \quad (\mu_x) \quad (3)$$

$$y_{lc} \geq 0 \quad (4)$$

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 x simultaneously will give a non-linear complementarity problem. We obtain the following Karush-Kuhn-Tucker (KKT) conditions of the optimization problem (1) - (4):[4]

$$0 \leq - p_m - b_m \cdot y_{xm} + \frac{\partial c_x}{\partial y_{xm}} + trans\_c_x \cdot \kappa_x + \lambda_x \cdot \kappa_x + \mu_x \cdot \kappa_x \qquad \perp y_{xm} \geq 0 \tag{5}$$

$$0 \leq prod\_cap_x - \sum_m \kappa_x \cdot y_{xm} \qquad \perp \lambda_x \geq 0 \tag{6}$$

$$0 \leq exp\_cap_x - \sum_c \kappa_x \cdot y_{xm} \qquad \perp \mu_x \geq 0 \tag{7}$$

We consider a strategic player that takes into account his influence on the demand function and whose derivative of the linear demand function is $\frac{\partial p_m(y_m)}{\partial y_{xm}} = b_m$. The term $b_m \cdot y_{xm}$ 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 $\frac{\partial p_m}{\partial y_{xm}} = 0$. We can therefore introduce a market power parameter α_x for each player x that is multiplied with the term $b_m \cdot y_{xm}$ and that is defined as $\alpha_x = 0$ for a competitive player x, and $\alpha_x = 1$ for a Cournot player. Indeed, α_x is nothing else than the conjectural variation of a player x reacting to its competitors $-x$.

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

$$p_m - p_m \left(\sum_x y_{xm} \right) = 0, \quad p_m \quad \text{(free)} \tag{8}$$

This complementarity model is programmed in GAMS, and solved with a standard algorithm for MCP (mixed complementarity problems), PATH.[5]

3.2 Data

This section details the parameter input for the two specifications of the model with respect to quantity and energy content. We use data for exports and imports at the country level, and assume each country to be one player.[6] Table 2 details the countries used in the data

[4] Following the standard literature of complementarity modeling, 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.

[5] Cf. Ferris and Munson (2000) for an overview.

[6] 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.

set, which are the main exporters and importers on the international steam coal market.[7]

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

As mentioned in Section 3.1, we assume a linear inverse demand function of the type $p_m = a_m + b_m y_m$ for each importer m. We construct a different linear inverse demand function for each importing country m using their reference prices (p_m^{ref}) and reference demand value ($y_m^{ref} = \sum_x y_{xm}^{ref}$) of each base year 2005 and 2006 and assumptions on the demand elasticities (ε_m). In particular, we define $b_m = \frac{p_m^{ref}}{y_m^{ref}} \cdot \frac{1}{\varepsilon_m}$ and $a_m = p_m^{ref} - b_m \cdot y_m^{ref}$, following the demand elasticity definition $\varepsilon_m = \frac{y_m - y_m^{ref}}{p_m - p_m^{ref}} \cdot \frac{p_m}{y_m}$. Given that the value of ε is usually negative, we have a positive intercept a and a negative slope b. This gives the following inverse demand function:

$$p_m = p_m^{ref} + \frac{1}{\varepsilon_m} p_m^{ref} \left(\frac{\sum_x y_{xm}}{y_m^{ref}} - 1 \right) \tag{9}$$

As shown in Table 1, the type of input needed for the two model specifications differs due to the different units used. For the CMT model, 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 (IEA, 2007). For the CMT-E model, we use the same base data and use additional coal quality data (Table 3). We convert the mass import flows obtained from IEA (2007) into energy flows and aggregate them to obtain a reference demand expressed in Petajoules ($10^{15} Joules$). The reference prices in USD/Gigajoules ($10^9 Joules$) are calculated by dividing the total value of imports by the demand in Petajoules. Demand elasticities ε_m are chosen in the calibration process data

[7] China and the United States of America are both, exporting and importing countries. Hence, they are introduced twice, as exporting and as importing country. This is because we focus on the international trade and do not aim at a representation of domestic markets. In order to keep the model consistent, the exporter and importer of the same country are not allowed to trade with each other. In this case, the importing and exporting port are different (USA: Mobile (AL) and Hampton Roads (VA), China: Shenzhen and Quinhuangdao).

(Table 3). We convert the mass import flows obtained from IEA (2007) into energy flows and aggregate them to obtain a reference demand expressed in Petajoules ($10^{15} Joules$). The reference prices in USD/Gigajoules ($10^9 Joules$) are calculated by dividing the total value of imports by the demand in Petajoules. Demand elasticities ε_m are chosen in the calibration process and based on Dahl (1993). In the benchmark specification we use $\varepsilon_m = -0.3$ for all countries.

In the CMT model, the production cost function of each exporter is assumed to be quadratic of the type $c_x = (ac_x + bc_x \cdot Y_x) \cdot Y_x$, with total production $Y_x = \sum_m y_{xm}$. Thus, the marginal cost function is $mc_x = ac_x + 2 \cdot bc_x \cdot Y_x$. The cost functions are obtained using data provided by RWE (2005) that gives lower and upper bounds on average costs for each exporter. We use this information to construct linear average cost curves. The intercept parameter ac_x corresponds to the lower bound. In order to determine the slope bc_x we use a second point defined by the maximum production capacity and the upper bound of the average costs assuming a linear average cost function $avc_x = ac_x + bc_x \cdot Y_x$. For the CMT-E model the additional conversion factor κ_x has to be added to the equations. Thus we obtain following marginal cost function $mc_x = \kappa_x \cdot ac_x + 2 \cdot \kappa_x^2 \cdot bc_x \cdot Y_x = \frac{\partial c_x}{\partial y_{xm}}$ that we can integrate in the KKT condition (5).

The unit seaborne transport costs $trans\_c_{xm}$ expressed in USD/t are based on observations of selected freight rates for each base year 2005 and 2006 and from the technical freight literature and IEA (2007). These observations were used in a regression to obtain linear functions of freight rates based on distance and then obtain the specific value of $trans\_c_{xm}$ for every possible route between the exporters and the importers.

Finally, data on production capacities is from Kopal (2007). This is production capacity that is available for exports (export mines). In addition, we include export capacity constraints. Export capacities are export harbor capacities and are based on RWE (2005) and VDKI (2006). We implicitly assume that shipping (boat) and import harbor capacity is available without capacity limitation.

	kcal/kg	GJ/t	κ_x in t/GJ
Australia	6400	26.80	0.03732
Indonesia	5450	22.82	0.04382
South Africa	6260	26.21	0.03815
Russia West	6400	26.80	0.03732
Russia East	6300	26.38	0.03791
China	6200	25.96	0.03852
Colombia	6375	26.69	0.03747
USA	12500[Btu/lb]	29.08	0.03439

Table 3: Coal quality data used for the CMT-E model (Source: Platts, 2008)

4 Market structure analysis

4.1 Cournot vs. competitive market

We would like to explore 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 (1984). This can give us an indication of whether import dependent countries must pay a higher price than the competitive price level, and whether they are subject to the exercise of market power by the exporters.

The models are 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_x. For the scenario of a perfectly competitive market, we set $\alpha_x = 0$ for all x; conversely, $\alpha_x = 1$ for all l in the Cournot scenario. We compare the results of our simulations with the observed trade flows in 2005 and 2006. We also compare the outputs from the two different model specifications in order to determine the influence of the additional quality information on the results.

Figure 1 and Figure 2 show the model results and actual trade flows in 2005 for the two specifications CMT and CMT-E, respectively. The results of the CMT-E model are converted from Petajoules to million tons using the coal quality data from Table 3. Total import quantities obtained in both models show a remarkable similarity of the perfect competition results with the reference data for 2005 and 2006. This is also true for 2006 (Figure 12 and 13 in the Appendix). The Cournot scenario, on the other hand, gives smaller quantities and considerably higher prices than observed in reality.

The detailed results for both years and both CMT and CMT-E models are presented in the Appendix. It is quite obvious that the number of flows (number of trading relations) in the perfect competition simulation results 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 diverse picture with each importer buying from virtually all exporters.

The results of the perfect competition scenario with little diversification are 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 and these higher prices attract a larger number of suppliers, including those with higher costs. 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 2005 results of both model specifications with prices shown in Figure 3, we see that the prices of the perfect competition simulations are closer or in the same

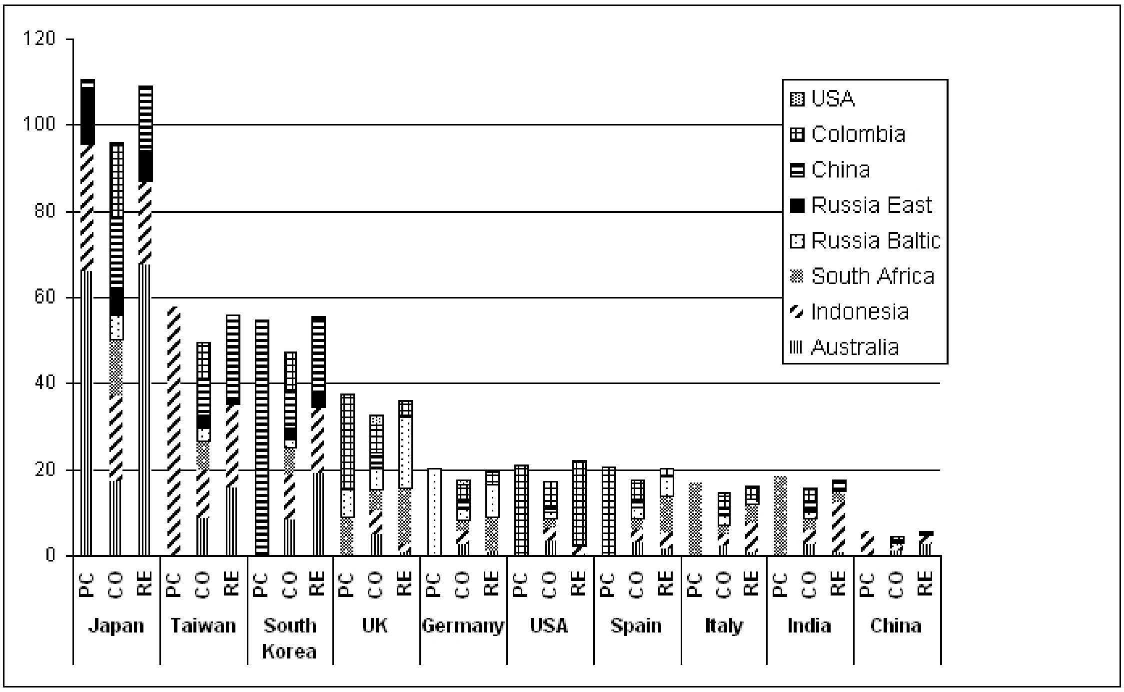

Figure 1: Imported quantities in the perfect competition (PC), Cournot scenario (CO), and reference data (RE) in 2005, in million tons (Mt) for the CMT model

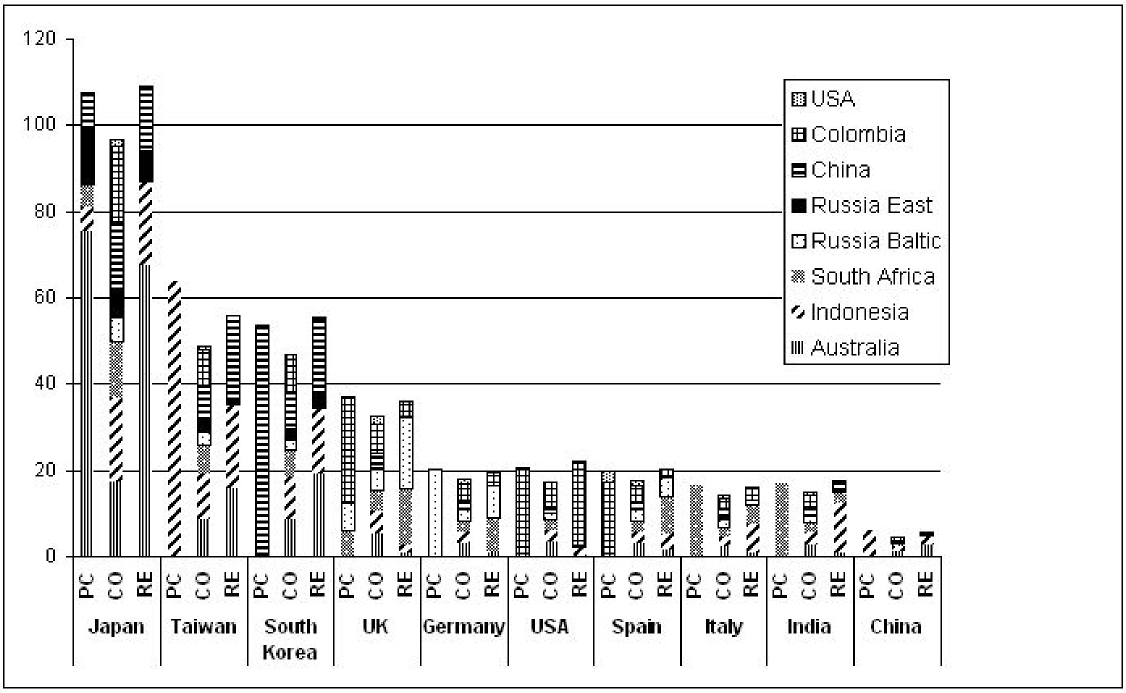

Figure 2: Imported quantities in the perfect competition (PC), Cournot scenario (CO), and reference data (RE) in 2005, in million tons (Mt) converted from Petajoules for the CMT-E model

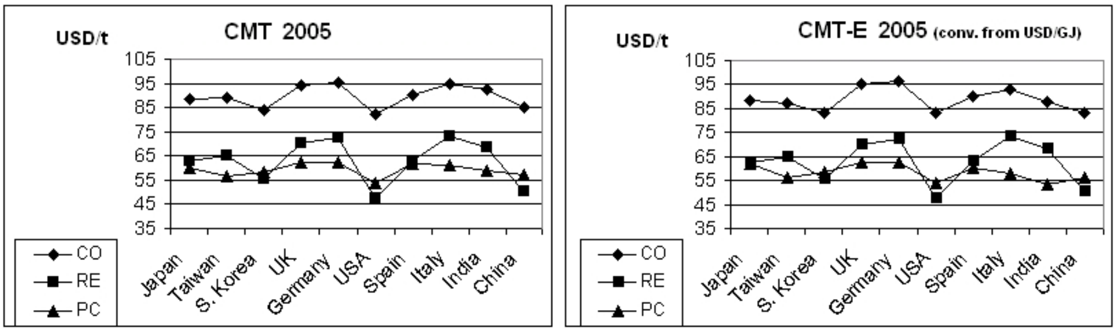

Figure 3: CIF Prices in the perfect competition (PC), Cournot scenario (CO), and reference data (RE) in 2005 for the CMT and CMT-E models, USD per ton

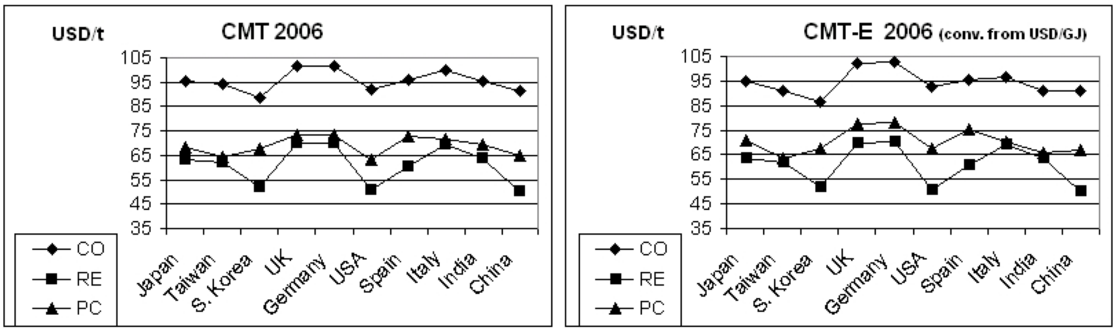

Figure 4: CIF Prices in the perfect competition (PC), Cournot scenario (CO), and reference data (RE) in 2006 for the CMT and CMT-E models, USD per ton

range as the real observed prices. However, the variation of the reference prices between the countries in reality is the same as in the Cournot simulation. Cournot competition allows for price discrimination whereas the perfect competition simulation does not. These two conclusions also apply to the prices in 2006 (see Figure 4). However, the price levels in the model results for 2006 are high, with even perfect competition prices above the real price level, which can be explained by a certain lag in pricing-in capacity constraints (see Section 4.2).

When comparing the quantity and energy specification, we observe that the CMT model's perfect competition results show significantly less supplies from Australia than in reality (2005: 66 Mt vs. 110 Mt, 2006: 62 Mt vs. 105 Mt). On the other hand, the CMT model results for the exports from Indonesia are higher than in reality by approximatively 10 Mt for both years. One explanation of these distortions is the fact that a quantity model does not incorporate information about the energy content of the coals. However, in the end, what is important for the customer is the energy contained in the coal. By not incorporating the quality information a distortion is created that makes lower quality coal, like the Indonesian coal, more attractive: the associated transport costs that are mass dependent are underevaluated in comparison to higher quality coals. In return, the same distortion makes higher quality coal like the Australian less attractive. This is confirmed by the perfect competition results of the CMT-E model which show higher Australian exports (75 Mt in 2005 and 73 Mt in 2006) and lower Indonesian exports.

Both model specifications provide 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 shows that for the purpose of a market structure analyses a quantity based model is sufficient. However, if one aims at a better representation of detailed trade flows, a model that incorporates both energy and mass quantity information is needed. This will remain true in the next decades as we expect an increase in the supply of lower quality coal to the world market.

In order to show the strength of our results we tested their robustness with respect to the parameter for which the underlying data is the weakest, the price elasticity of demand. We performed a sensitivity analysis of the prices for different elasticity values. The results are shown in Figure 5.

The perfect competition are much more robust than the Cournot results when we vary the elasticity of demand ε_m, in 2005 they are so close that we cannot distinguish them graphically. Also, the higher the elasticity, the closer the Cournot competition model price results get to the real prices. However they are still significantly higher and since $\varepsilon_m = -0.6$ is really the highest limit of demand elasticity we can assume from the literature the perfect competition modeling results still better represent reality.

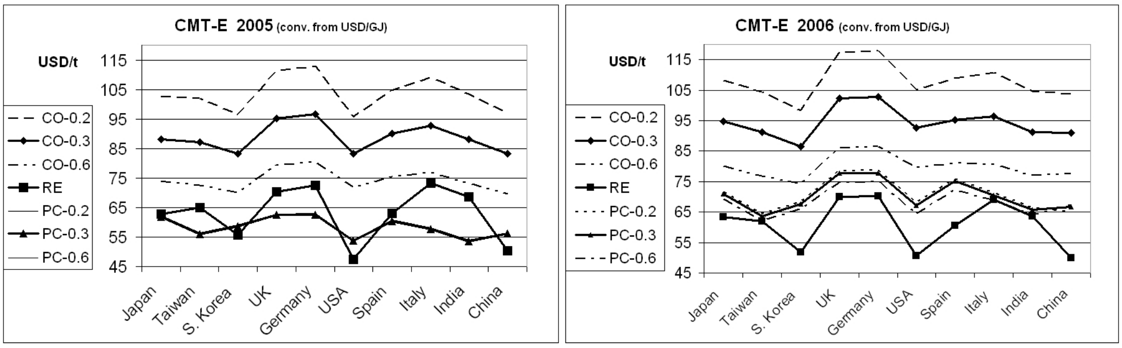

Figure 5: CIF Prices in the perfect competition (PC) and Cournot scenario (CO) model results for different elasticity values, and reference data (RE) in 2005 and 2006 for the CMT-E model, USD per ton

4.2 Pricing and export restrictions in a temporal perspective

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_x and μ_x of the capacity constraints (2) and (3), respectively, points to a capacity limitation for exporter x. Bottlenecks can potentially indicate in which exporting countries there is need for investment in the producing and exporting infrastructure. The results of both specifications allow a similar interpretation about pricing and export restriction. For this reason the interpretations in this section will only refer to the perfect competition results of the CMT-E model specification.

The results of the CMT-E model show positive dual prices μ_x for South Africa, Russia (Baltic and East), and Colombia in 2005 and for South Africa, Russia Baltic, China and Colombia in 2006. This means that in the model, all these countries reached their maximum export capacity. Production capacity constraints were not binding because they are higher than the export capacity constraints for all these countries. Also, the level of the dual prices μ_x was significantly higher in 2006 than in 2005. The sum of the dual prices μ_x of all exporters in 2005 was 26.86 USD/t and 72.70 USD/t in 2006. This is the main reason why the model calculates a higher average price of 73.31 USD/t in 2006, compared to 58.31 in 2005, despite a lower average of the reference demand prices in 2006 (61.12 UDS/t and 62.86 UDS/t in 2005). Figure 6 sheds some light on the German import price and the European spot price around 2006.

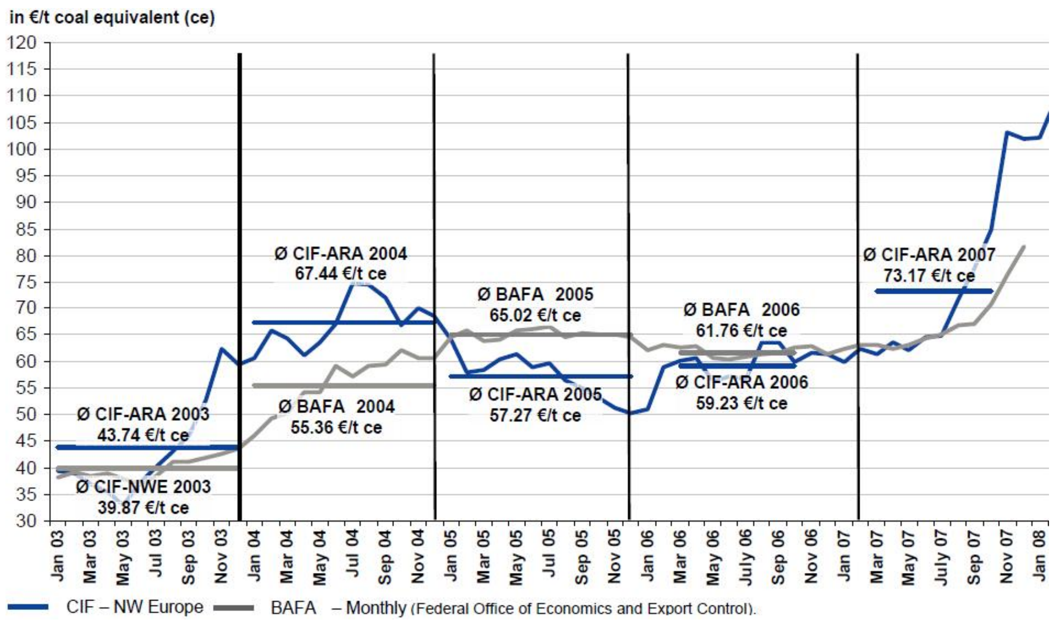

Figure 6: Historical steam coal prices: CIF(cost insurance freight) spot price in ARA (Amsterdam-Rotterdam-Antwerpen) and price of delivered steam coal at the German border (Source: RWE, 2008)

The darker curve represents the historical spot price to Northwest Europe and the grey curve shows prices reported by the German Federal Office of Economics and Export Control (BAFA) when the steam coal crosses the German border. We observe that the BAFA price follows the CIF-ARA price with a few months time lag. Also, there seems to be an asymmetric price adjustment in response to a rise of the spot price that is higher than the response to a decline.[8] The CIF-ARA spot price represents the price for deliveries

[8]This phenomenon is somewhat similar to the "rockets and feathers" situation in retail gasoline prices

in the forward 90 days period. It is not a typical commodity exchange price like for the major commodities but a price index based on a weekly survey of a limited number of deals submitted by industry participants. Since this represents the participants' individual view of the state of the market, the quality of this price signal and its reaction time to market developments is not as good as for other commodities. Since the prices from IEA (2007) used in our model are reported customs prices like the BAFA prices we must carefully assess the price developments, their role as indicators of export capacity scarcity and their function as price signals for new investments.

The rising prices in the global steam coal market since 2003 triggered investments in export mine capacities in 2004 (Kopal, 2007) that explain the decreasing CIF-ARA prices and the stabilization of the BAFA prices in 2005. Like the average reference demand prices in our data input, the BAFA prices are slightly lower in 2006 than in 2005. But on the spot market the downward trend of 2005 did not persist and in 2006 the price increased. This was due to an increased demand that was not met by sufficient investments. This explains why the 2005 model prices were in the range of the observed prices whereas the 2006 prices where higher. In 2005, the supplies were hardly constrained and prices were on a downward trend. In 2006, a higher demand and insufficient capacities were not fully incorporated into the real market pricing but the model results already account for them. Thus, our simulated prices are consistent with the upward trend in CIF-ARA spot prices for 2006 and signal the price explosion that occurred in 2007.

The pricing in the international market seems to lag the real market developments and thus makes it difficult to send the right investment signals in time. This is due to the fact that the international coal market is still intransparent and lacks the liquidity of other commodity markets. Another possible reason why bottlenecks can occur is that the players withhold capacities in the long-run to sell low quantities and obtain high prices. However, bottlenecks can also occur when the demand rises abruptly because investments to expand production and export capacities cannot be done in the short term. The observed lag in prices as well as the poor quality of the price signal accentuates this effect. The observed demand increases in China and India but also in the USA and Europe in the last years and a tighter supply situation due to insufficient investment explain the price increase on the international steam coal market.

In a competitive framework, the players 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. 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 (2007) also describes that bottlenecks in the coal sector have not been lasting in

which has been extensively studied.

the last decades and that the industry has been reactive to investment signals.

5 Scenario analyses

5.1 Model Assumptions and Scenario Overview

While the previous sections showed that there is little threat for the coal importers from market power exerting exporters, we shall analyze the impacts of possible disruptions on the market. In fact, some of the large exporting countries may be considered as "risky" in terms of their political stability (South Africa, Indonesia) or their geopolitic role in energy markets (Russia). However, it must be noted that there have been only few incidents of supply disruption in the past that were due to (geo-) political issues; often, technical, meteorologic or labor organizational problems are the source for temporary disruptions. But since the risk of disruption is perceived as increasing in other energy markets (e.g., natural gas), we would like to explore the potential impacts for coal markets, too. We study scenarios of disrupted exports from, respectively, South Africa and Russia, two very important suppliers to Europe, and from Indonesia, the largest exporter in the world.

Moreover, there is quite some uncertainty on the demand development, in particular in the large developing countries China and India. Their "hunger for energy" has been one of the major reasons for the skyrocketing energy prices in 2008. While the economic crisis has somewhat attenuated the growth in demand in China and India for the time being, an acceleration of the economic growth is likely to bring another sharp increase in demand for fuels. Coal, as a cheap and domestically available energy source, is a privileged fuel in both, the Chinese and the Indian economy. In addition to their domestic production, both countries rely on the import market to a small but remarkable extent. The amount of imports can easily double in an economic boom, and we hence simulate a doubling of the reference import demand in the first scenario.

In the following, we assume that the market is competitive as is shown in the previous sections. We use the energy-based model specification, as this model gives more precise insights into the market trends. We limit ourselves to the year 2006 for the following scenarios in order to use the most recent data. Hence, we define the results of the energy-model specification of a perfectly competitive market in 2006 from Section 4.1 to be the "Base Case". The base case results can be found in the Appendix in Figure 13 (in Mt) and Tables 16 and 17 (in PJ). The results of the counterfactual scenario simulations are compared to this base case. Figure 7 gives a first overview and shows the price development in all scenarios, compared to the base case results and real observed data. At first sight, we can notice that a disruption of the Indonesian exports would have the strongest impact on the world market and that the Russian disruption affects the European importers markedly, too.

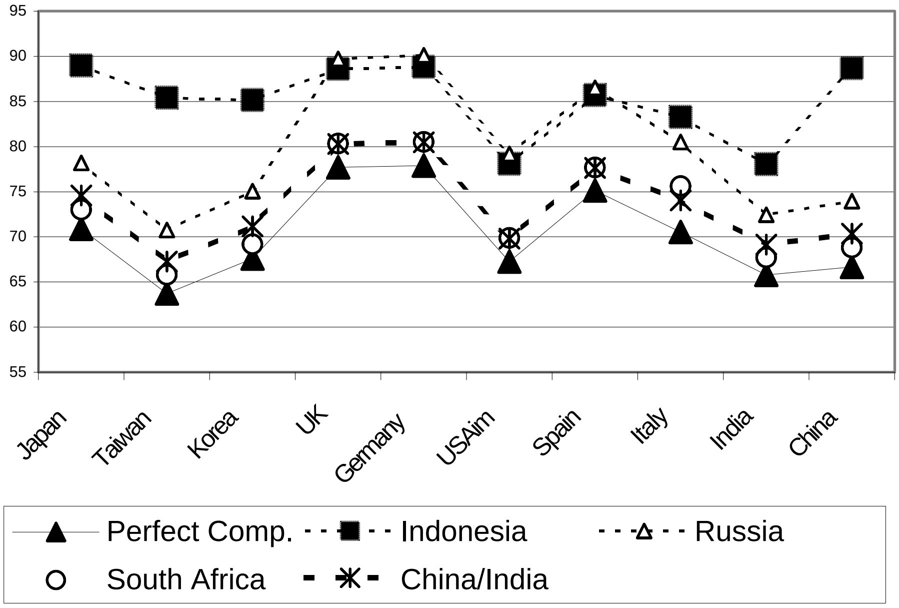

Figure 7: CIF import prices in USD for all scenarios and perfect competition base case

5.2 Scenario 1: Doubling Demand in India and China

China and India are fast growing emerging countries with a strongly rising demand for energy. Their import demand can be expected to have a noticeable impact on the international steam coal market. We investigate the case of a doubling of the coal import demand in China and India. Therefore we multiply the reference quantity y_m^{ref} (in energy values), used in constructing the import demand function, of 176.49 PJ for China and 518.86 PJ for India by two. All other data is left unchanged.

Figure 8 shows the differences of the scenario results to the base case (perfect competition) results. As expected, imported quantities in the two countries nearly double. While in the base case China imports 6.34 Mt, it is now importing 12.12 Mt. The same is true for India with imports going up from 19.74 Mt to 40.78 Mt.

European importers are hardly affected. There is a cutback of imports of only 1.57 Mt for all European importers, this is a difference of less than 2%. The largest impact can be seen in Asia. Japan is the worst affected by the demand increase because it loses a part of its imports delivered by Indonesia in the base case. This part of 14.58 Mt is not fully compensated by other suppliers. Australia and East Russia deliver only 5.6 Mt more to the world market than in the base case. Indonesia supplies the major share of the demand increase in both India and China.

The change in prices is shown in Figure 7. The average price in the world rises by 5%.

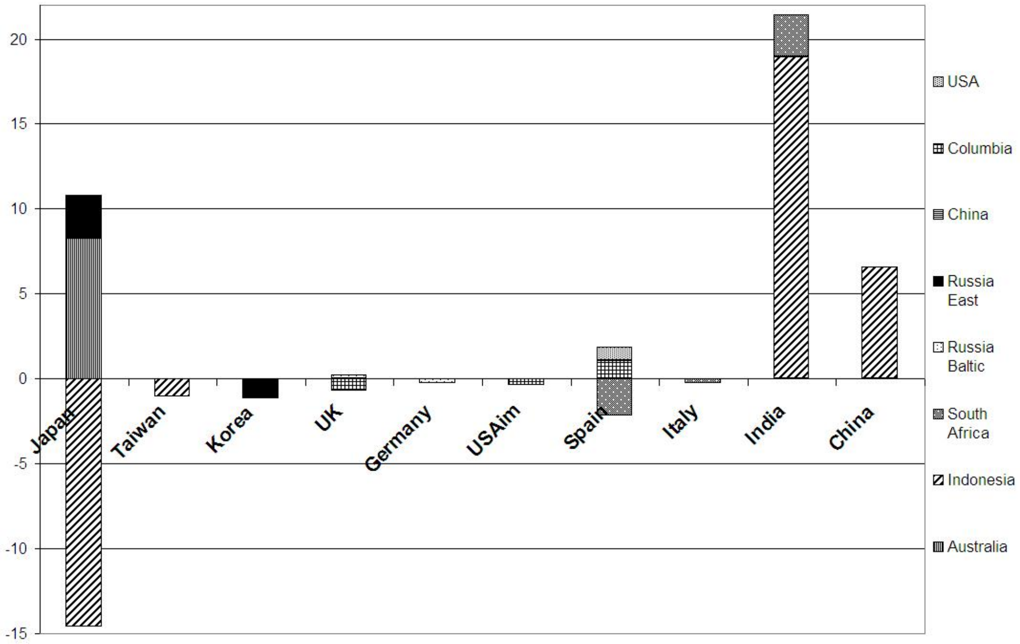

Figure 8: Difference in supply in million tons (Mt) compared to the base case. Scenario: Doubling demand in India and China

Taiwan is affected the worst, its price rises by 3.54 USD (6%). Europe is affected under average (plus 3.7%).

5.3 Scenario 2: Export Disruption from Indonesia

Indonesia has become a major player in the world market for steam coal in the last years, now at an equal level with the traditional leader Australia. It is a particularly important supplier to the Asian importers - China, Taiwan, Japan - which have adapted their consumption in power plants to the Indonesian coal quality (lower energy content than internationally traded coal usually has). The Indonesian exports in the base case are 88 Mt in 2006, which is a fourth of the total international trade. Hence, we can expect a major impact from a disruption of Indonesian suppliers. In this scenario we implement a complete stop of exports from Indonesia. In terms of model adaptation, this means that we set the value for Indonesia's export capacity zero. All other data is left unchanged.

Figures 9 and 7 show the significant impact of an Indonesian disruption. It is, in fact, the scenario with the largest effect on prices. As can be expected, the Asian market and in particular Taiwan and Japan are affected the most. In Taiwan, the whole import demand is satisfied by Indonesia in the base case. In the scenario, the Taiwanese CIF price is more than 25 USD/t (34%) higher than in the base case because it can substitute only a part of Indonesian coal deliveries with imports from other suppliers. Japan can also not substitute all Indonesian coal, but its price is a little less affected than Taiwan's (plus

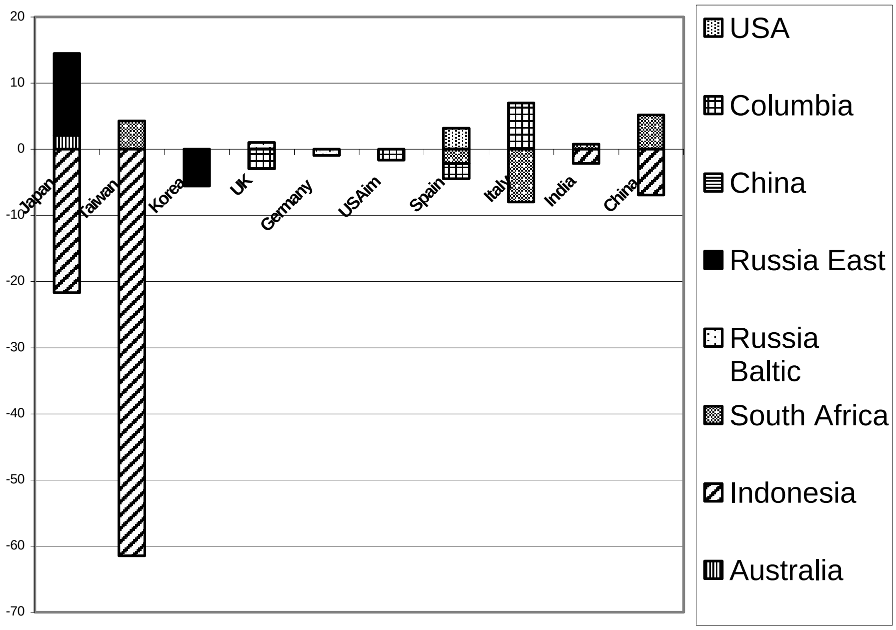

Figure 9: Difference in supply in million tons (Mt) compared to the base case. Scenario: Export disruption in Indonesia

25%). Similarly, China is also fully supplied by Indonesia in the base case (see Figure 13) and it can compensate them with South African imports in the scenario. China still suffers a price increase of 33%.

The average price on the international market is 21% higher than in the base, 15% (about 11 USD/t) higher in Europe. There are 14.3 Mt less delivered to Europe than in the base case, this is about 7% import decrease. The decrease in Europe is not due to a direct failure of Indonesian exports to Europa. It rather happens because traditional suppliers to Europe (e.g., Colombia, South Africa) turn to the Asian market to compensate for the missing Indonesian export coal. Despite the substitution effects, the total loss in consumption in this scenario is almost 85 Mt, that is approximately the amount of the missing Indonesian exports and a quarter of the international trade in the base case.

5.4 Scenario 3: Export Disruption from Russia

It seems unlikely that Russia would curtail its coal exports for (geo-) political reasons, unlike in the natural gas sector. Rather, technical problems, for example in the internal rail system, could occur and hamper coal exports. In the long run, there are discussions in Russia to substitute gas by coal in the domestic power generation and to export gas instead of coal to benefit from the higher gas price and from the absence of a climate emissions target for Russia. In this scenario, we set the export capacity of both Russian

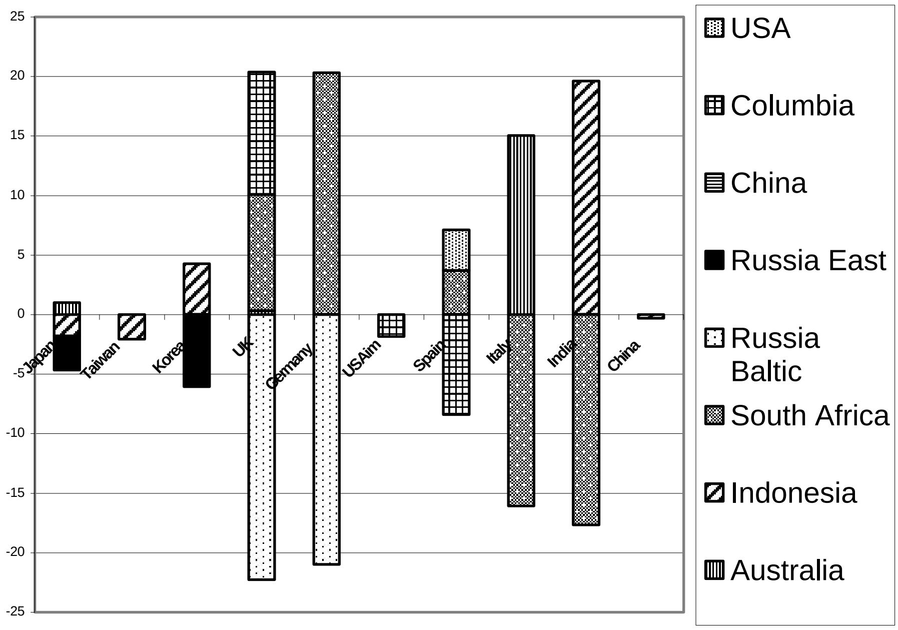

Figure 10: Difference in supply in million tons (Mt) compared to the base case. Scenario: Export disruption in Russia

exporters (Russia-West on the Baltic sea coast, and Russia-East on the Pacific coast) to zero.

In the base case, Russia delivers about 15% of the world's international coal trade, with the major share going into the Atlantic basin via the Baltic Sea. We observe effects of the Russian curtailment in both regional basins. In the Atlantic basin, the importers of Russian coal, chiefly UK and Germany in the base case, loose their imports from Russia and substitute them with imports from Columbia and especially South Africa (Figure 10). The indirect effect is that there are less South African exports available to Italy and India, that compensate the failure with Australian (Italy) or Indonesian (Indian) coal, depending on their willingness to pay. At the same time, the Columbian exports to the UK are no longer going to Spain that imports from South Africa and Australia instead. In the Pacific basin, Japan and Korea loose the Russian coal and partially compensate for it with coal from Indonesia (Korea). Indonesia and Australia have some spare capacity to respond to the additional demand after Russia's disruption. That is why the total loss in imports is only about 12.5 Mt (4% of the base case imports).

This picture is confirmed by the price results in Figure 7. A Russian disruption primarily has an impact on the European importers: the prices in Germany and the UK are about 15% higher than in the base case. Only small amounts of Russian coal are at the moment exported to Asia and, hence, there is little direct effect. However, due to the

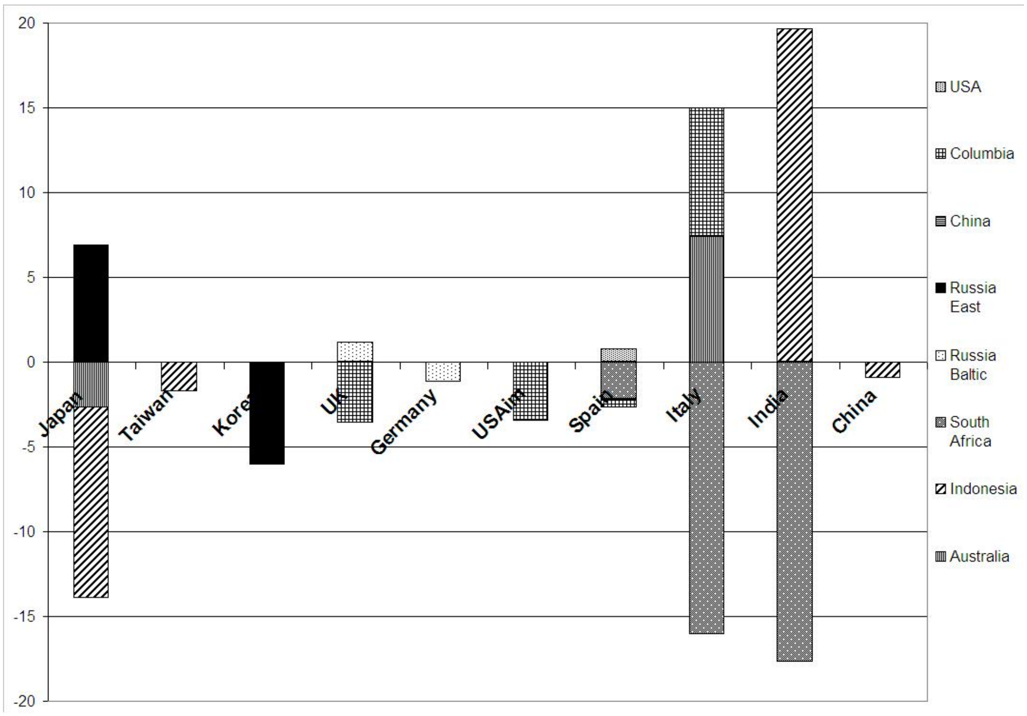

Figure 11: Difference in supply in million tons (Mt) compared to the base case. Scenario: Export disruption in South Africa

increased demand for coal from Indonesia and Australia, all importers in the world are affected by a generalized price increase of 13% on average.

5.5 Scenario 4: Export Disrupton from South Africa

In the last disruption scenario, we focus on South Africa. Here again, there have been hardly any supply failures in the past, but there may be some risk of disruption due to national energy policies and technical problems. On the technical side, South Africa has problems to maintain and expand its inland coal rail system to bring the coal from the mines to the export harbor. Moreover, there is only one export terminal (Richard's Bay) in the country. The national energy policy in South Africa has been rather volatile in the last years: after abandoning the plan to construct nuclear power in response to the strong increase in electricity demand, the future energy mix is somewhat unclear now. It is likely that coal with continue to be the major fuel. Given the shortages in the South African energy system, evidenced by multiple large black-outs in the last years, there may be a risk that electricity supply is increased in the short run by using coal destined for the export market. Here, we analyze such a situation where South Africa doesn't supply any coal any more to the world market.

Figure 11 shows the effect on the traded quantities. Italy and India as importers of South African coal in the base case are strongly affected, but they can substitute with imports from Indonesia (India) and Australia and Columbia (Italy). However, this in turn has a negative effect on the imports of all other countries, that have to reduce their consumption of coal from Indonesia, Australia and Columbia. An additional shifting effect of (West) Russian coal can be seen between Japan and Korea. In total, 24 Mt (7%) of coal less than in the base are available on the world market. Just as in the previous scenario, the availability of some spare capacities in Indonesia and Australia reduces the total impact on the market.

The prices (in Figure 7) confirm the relatively modest impact of the South African disruption. The price increase is in the order of magnitude of the first scenario, with on average 3.6% higher prices than in the base case. Italy suffers the strongest price increase, but it is still small with about 7%.

6 Conclusions

We have presented two complementarity models 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 for our two model specifications based only on quantities and based on the energy content of the coal. 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 (1984) 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.

The overall results of the market structure analysis to do not differ between the two model specifications. However, we find that using a model that is only based on quantities leads to distortions in the detailed trade flows with respect to the transport costs: it makes lower quality coal more attractive and higher quality coal less attractive to the importers. This distortion can be corrected using an energy and quantity model.

In addition to the market structure analysis, we have studied the pricing on the international steam coal markets. We have found evidence that there exists a time-lag in the pricing of export capacity constraints. The reaction of the market prices to supply constraints is delayed and the poor quality of the price indexes makes it difficult to fully represent the current market situation. This may explain how prices can fail to provide the right investment signals or, in the shorter term, fail to give incentives for consumers to find alternative supply sources quickly. Such delayed adjustments can explain how price spikes as we have seen in 2007 and 2008 can occur.

Using the model, we have performed several scenario simulations. On the one hand, we have investigated the impact of an import demand increase of China and India, the two emerging countries with an unsatiable "hunger for energy". On the other hand, we have studied the effect of several disruption cases of some important steam coal exporters, Indonesia, South Africa and Russia. A disruption from Indonesia, one of the largest steam coal exporters in the world, would affect the entire global market the most strongly, with a marked price impact, but the Asian region would be particularly affected. The European importers, especially UK and Germany, would see a higher impact, in terms of prices, from a disruption of Russian exports. In all scenarios, the European importers can almost fully compensate for the failing exports with supplies from other countries. The large Asian importers, especially Japan and Taiwan, can substitute failing exports to a much lower extend and are strongly dependent on Pacific basin supplies.

We conclude this report by remarking that there is little risk to supply security in coal from the international steam coal market. The steam coal exporters do not exert oligopolistic market power and pricing is rather competitive. There are some delays in investment as adjustment to demand increases, but Kopal (2007) showed that such investment cycles have been characteristic of the coal market in the last decades and that the cycles tend to go to a point of over-capacity. Moreover, we have seen in the scenario analysis that the European importers have access to a diverse set of coal suppliers, and that they therefore are able to compensate failing supplies in case of a disruption. The picture is somewhat different for the large Asian importers Japan and Taiwan that depend strongly on Indonesia. The model allows us to identify not only direct export failure but also compensation and substitution effects. In future research, our partial equilibrium modeling approach should be combined with an energy systems model such as POLES in order to investigate the interdependencies not only between coal countries but also between fuels.

References

Aune, Finn Roar, Rolf Golombek, Sverre A. C. Kittelsen, Knut Einar Rosendahl and Ove Wolfgang. 2004. "Liberalizing the Energy Markets of Western Europe - A Computable Equilibrium Model Approach." *Applied Economics* 36(19):2137–2149.

Dahl, Carol. 1993. "A Survey of Energy Demand Elasticities in Support of the Development of the NEMS." Colorado School of Mines.

Egging, Ruud, Steven A. Gabriel, Franziska Holz and Jifang Zhuang. 2008. "A Complementarity Model for the European Natural Gas Market." *Energy Policy* 36(7):2385–2414.

EIA. 2007. "Coal Market Module of the National Energy Modeling System - Model Documentation 2007."

Ellerman, A. Denny. 1995. "The World Price of Coal." *Energy Policy* 23(6):499–506.

Ferris, Michael C. and Todd S. Munson. 2000. "Complementarity Problems in GAMS and the PATH Solver." *Journal of Economic Dynamics and Control* 24(2):165–88.

Haftendorn, Clemens and Franziska Holz. 2008. "Analysis of the World Market for Steam Coal Using a Complementarity Model." *DIW Discussion Paper* 818.

Holz, Franziska, Christian von Hirschhausen and Claudia Kemfert. 2008. "A Strategic Model of European Gas Supply (GASMOD)." *Energy Economics* 30(3):766–788.

IEA. 2007. *Coal Information 2007*. Paris: OECD.

Kolstad, Charles D. and David S. Abbey. 1984. "The Effect of Market Conduct on International Steam Coal Trade." *European Economic Review* 24(1):39–59.

Kolstad, Charles D., David S. Abbey and Bivins Robert L. 1983. "Modeling International Steam Coal Trade." Los Alamos National Laboratory.

Kopal, Christopher. 2007. "Entwicklung und Perspektive von Angebot und Nachfrage am Steinkohlenweltmarkt." *Zeitschrift für Energiewirtschaft* 31(1):15–34.

Li, Raymond. 2008. "International Steam Coal Market Integration." Department of Economics, Macquarie University, Australia.

Platts. 2008. "Methodology and Specifications Guide - Coal."

Rademacher, Maggi. 2008. "Development and Perspectives on Supply and Demand in the Global Hard Coal Market." *Zeitschrift für Energiewirtschaft* 32(2):67–87.

RWE. 2005. "World Market for Hard Coal, 2005 Edition."

RWE. 2008. "Facts and Figures - Update May 2008."

Samuelson, Paul A. 1952. "Spatial Price Equilibrium and Linear Programming." *American Economic Review* 42(3):283–303.

Takayama, T. and G.G. Judge. 1964. "Equilibrium Among Spatially Separated Markets: A Reformulation." *Econometrica* 32(4):510–524.

VDKI. 2006. *Jahresbericht 2006*. Verein der Kohlenimporteure.

Warell, Linda. 2006. "Market Integration in the International Coal Industry: A Cointegration Approach." *Energy Journal* 27(1):99–118.

Yang, Chin W., Ming Y. Hwang and Soong N. Sohng. 2002. "The Cournot Competition in the Spatial Equilibrium Model." *Energy Economics* 24(2):139–154.

Appendix

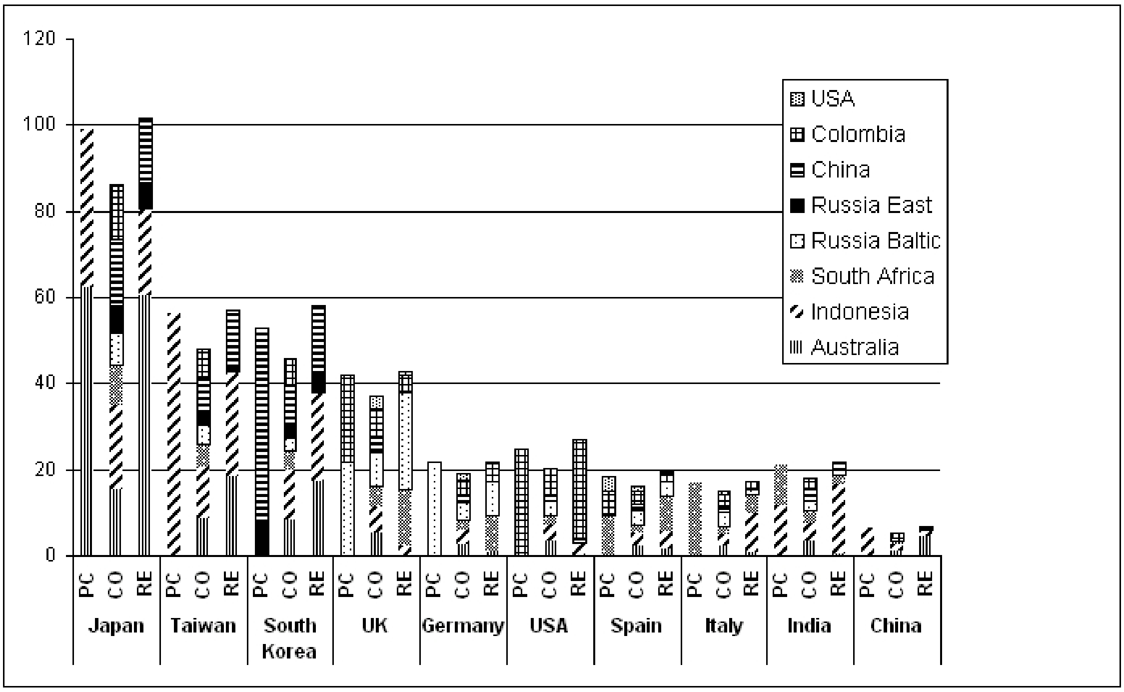

Figure 12: Imported quantities in the perfect competition (PC), Cournot scenario (CO), and reference data (RE) in 2006, in million tons (Mt) for the CMT model

	Cournot simulation	Perfect competition simulation	2005 CIF Prices
Japan	88.30	60.21	62.73
Taiwan	89.05	56.76	(65e)
South Korea	84.12	58.26	55.76
UK	94.06	62.37	70.24
Germany	95.14	62.14	72.48
USA	82.18	53.71	47.39
Spain	90.06	61.74	62.94
Italy	94.91	61.03	73.20
India	92.69	59.04	68.50
China	84.92	57.01	50.39

Table 4: Simulated import prices for the CMT model and reference CIF prices for 2005, in USD per ton

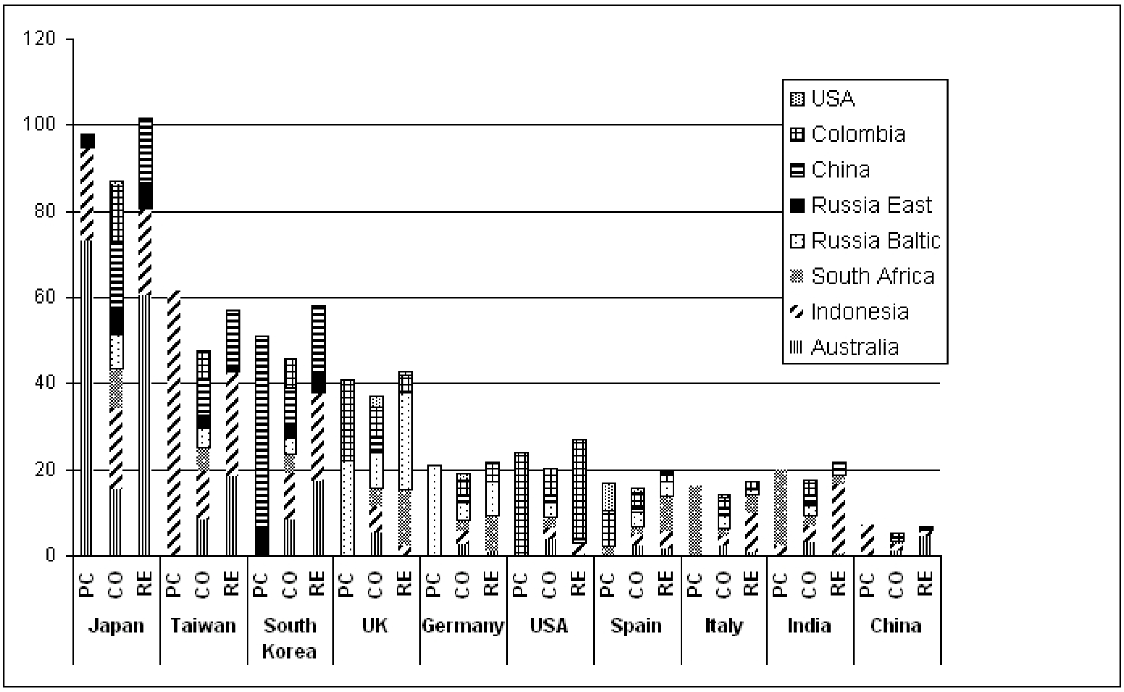

Figure 13: Imported quantities in the perfect competition (PC), Cournot scenario (CO), and reference data (RE) in 2006, in million tons (Mt) converted from Petajoules for the CMT-E model

	Japan	Taiwan	S. Korea	UK	Germany	USA	Spain	Italy	India	China
Aus.	66.06									
Indo.	29.68	57.83								5.48
R.S.A				9.11				16.97	18.27	
Ru.W.				6.18	20.39					
Rus.E.	13.02									
China	1.84		54.81							
Col.				22.06		21.12	19.87			
USA							0.65			

Table 5: Steam coal trade flows in the 2005 perfect competition scenario for the CMT model, in million tons (Mt)

	Japan	Taiwan	S. Korea	UK	Germany	USA	Spain	Italy	India	China
Aus.	17.08	8.76	8.38	5.05	2.74	3.20	2.84	2.35	2.79	0.99
Indo.	20.03	10.93	10.43	5.41	2.93	3.02	3.07	2.51	3.23	1.29
R.S.A	13.03	6.87	6.29	4.80	2.61	2.56	2.69	2.20	2.54	0.77
Ru.W.	5.63	3.22	2.06	5.03	2.74	1.39	2.61	2.15	1.44	0.29
Rus.E.	6.17	2.79	2.64	0.25	0.22			0.29	0.44	0.20
China	16.32	8.36	8.67	3.49	1.92	1.61	1.86	1.68	2.04	
Col.	17.37	8.49	8.61	6.47	3.43	5.38	3.74	2.79	2.79	0.98
USA	0.30	0.10		1.97	1.13		0.95	0.74	0.41	

Table 6: Steam coal trade flows in the 2005 Cournot scenario for the CMT model, 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 7: 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	63.70
China	91.31	64.67	50.00

Table 8: Simulated import prices for the CMT model 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 9: Steam coal trade flows in the 2006 perfect competition scenario for the CMT model, 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 10: Steam coal trade flows in the 2006 Cournot scenario for the CMT model, 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 11: Actual steam coal trade flows in the base year 2006, in million tons (Mt)

	Cournot simulation	Perfect competition simulation	2005 conv. CIF Prices
Japan	3.40	2.38	2.42
Taiwan	3.46	2.23	(2.58e)
South Korea	3.27	2.31	2.19
UK	3.61	2.36	2.66
Germany	3.64	2.36	2.73
USA	3.17	2.04	1.80
Spain	3.48	2.34	2.44
Italy	3.71	2.31	2.93
India	3.67	2.24	2.86
China	3.32	2.24	2.01

Table 12: Simulated import prices for the CMT-E model and converted reference CIF prices for 2005, in USD per Gigajoules

	Japan	Taiwan	S. Korea	UK	Germany	USA	Spain	Italy	India	China
Aus.	2019									
Indo.	130	1458								138
R.S.A	134			152				429	447	
Ru.W.				172	540					
Rus.E.	343									
China	222		1390							
Col.				662		555	465			
USA							68			

Table 13: Steam coal trade flows in the 2005 perfect competition scenario for the CMT-E model, in Petajoules (PJ)

	Japan	Taiwan	S. Korea	UK	Germany	USA	Spain	Italy	India	China
Aus.	463	228	226	141	77	92	78	61	69	26
Indo.	443	240	225	116	63	55	63	52	66	28
R.S.A	343	175	166	129	70	70	71	56	61	20
Ru.W.	152	87	61	133	73	38	68	54	37	9
Rus.E.	158	73	71	6	5			10	14	6
China	423	209	223	92	51	43	49	43	50	
Col.	469	221	231	178	95	148	100	72	69	26
USA	39	24		58	33		29	23	18	0

Table 14: Steam coal trade flows in the 2005 Cournot scenario for the CMT-E model, in Petajoules (PJ)

	Japan	Taiwan	S. Korea	UK	Germany	USA	Spain	Italy	India	China
Aus.	1806	424	515	25	21	2	38	18	22	66
Indo.	445	437	351	37		51	86	155	266	55
R.S.A	1	9		342	215	2	229	115	62	
Ru.W.				451	201	10	113	29		
Rus.E.	189	20	80							22
China	394	510	456	3		0	1		67	
Col.				88	78	514	52	80		
USA			11	9	4		7	6	2	0

Table 15: Actual steam coal trade flows in the base year 2005, converted in Petajoules (PJ)

	Cournot simulation	Perfect competition simulation	2006 conv. CIF Prices
Japan	3.66	2.74	2.45
Taiwan	3.67	2.56	(2.49e)
South Korea	3.44	2.69	2.06
UK	3.87	2.94	2.64
Germany	3.87	2.93	2.64
USA	3.53	2.56	1.92
Spain	3.70	2.92	2.35
Italy	3.92	2.87	2.81
India	3.85	2.78	2.69
China	3.51	2.57	1.93

Table 16: Simulated import prices for the CMT-E model and converted reference CIF prices for 2006, in USD per Gigajoules

	Japan	Taiwan	S. Korea	UK	Germany	USA	Spain	Italy	India	China
Aus.	1960									
Indo.	496	1404							50	159
R.S.A							58	422	464	
Ru.W.				597	563					
Rus.E.	76		161							
China			1168							
Col.				497		637	225			
USA							182			

Table 17: Steam coal trade flows in the 2006 perfect competition scenario for the CMT-E model, in Petajoules (PJ)

	Japan	Taiwan	S. Korea	UK	Germany	USA	Spain	Italy	India	China
Aus.	411	220	223	144	74	100	62	58	81	31
Indo.	432	261	247	130	67	62	56	54	86	37
R.S.A	242	139	117	127	65	65	54	50	66	18
Ru.W.	213	124	98	216	112	94	91	76	61	16
Rus.E.	166	75	74					4	13	7
China	399	216	236	91	46	46	36	39	59	
Col.	337	169	173	185	95	163	82	65	67	23
USA	35	10		81	42		32	27	18	

Table 18: Steam coal trade flows in the 2006 Cournot scenario for the CMT-E model, in Petajoules (PJ)

	Japan	Taiwan	S. Korea	UK	Germany	USA	Spain	Italy	India	China
Aus.	1619	494	465	4	19	4	42	24	12	119
Indo.	461	554	472	49		65	92	199	366	32
R.S.A	2	2		343	223	1	215	125	58	
Ru.W.				604	220	23	97	22		
Rus.E.	161	34	104							25
China	383	331	406	1		1	0		83	
Col.				109	107	614	41	54		
USA			16	23	14		13			

Table 19: Actual steam coal trade flows in the base year 2006, converted in Petajoules (PJ)