Institute of Energy Economics
at the University of Cologne

EWI Working Paper, No. 11/04

Nations as strategic players in global commodity markets: evidence from world coal trade

by
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June 2011

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Abstract

We explore the hypothesis that export policies and trade patterns of national players in the steam coal market are consistent with non-competitive market behavior. We test this hypothesis by developing an equilibrium model which is able to model coal producing nations as strategic players. We explicitly account for integrated seaborne trade and domestic markets. The global steam coal market is simulated under several imperfect market structure setups. We find that trade and prices of a China - Indonesia duopoly fit the real market outcome best and that real Chinese export quotas in 2008 were consistent with simulated exports under a Cournot-Nash strategy.

Keywords: Strategic national trade, imperfect competition, steam coal, China, Indonesia

JEL : L13, L71, C61, F10

ISSN : 1862 3808

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1. Introduction

Recently, the development of global commodity prices has given serious cause for concerns about the competitiveness of global commodity markets. This is especially true for natural resource markets and the trade of fossil energy fuels in particular. While the foundation of OPEC in the 1960s can be viewed as a well-known case for promoting strategic trade- and resource extraction policies, other markets for natural resources have been politicized just recently. A prominent example is the rare earth elements industry in China. Since 2008/09, the Chinese government made significant efforts to bring this resource sector under tight control by industry consolidation, creation of strategic stocks and, most importantly, by imposing trade restrictions upon exports of rare earth elements. Whether the aim of this policy was indeed the conservation of domestic resources or the preparation of monopoly power exploitation against high technology nations as

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Japan and the West has been recently discussed (Hurst, 2010; Stone, 2009). Both examples also indicate the variety of trade policy instruments. Next to cartelization and export quotas, governments levy taxes on imports or subsidize exports. On markets where production takes place by a large number of small units (e.g. for agricultural products), marketing of exports is often conducted by trade associations. On other markets, exporting firms might be partly or entirely nationalized, being subject to governmental strategic influence (for instance natural gas exporters). Such trade policy instruments are intended to increase national welfare by influencing the market outcome in a non-competitive manner.

Another commodity market that raised doubts about its competitiveness is the market for internationally traded steam coal (Trüby and Paulus, 2011). For decades, international coal trade has been considered competitive since production is geographically dispersed and is carried out by a blend of multinational private mining companies, large state-run entities and various smaller national players. Yet, recent developments in international steam coal trade have lead to concerns about market structure and conduct. And indeed, several institutional developments support the hypothesis of steam coal market distortion. Firstly, strong economic growth in Asia has lead to increased coal demand and thus shifted the center of gravity and price setting from the Atlantic to the Pacific market area. Secondly, coal prices soared between 2006 and 2008 and remained relatively high since then. Thirdly, several recent adjustments of national resource strategies of the People's Republic of China and Indonesia indicate an increasing potential for strategic behavior on a national level in recent years[1].

During the period of the 11th Five Year Plan (2005-2010) the People's Republic of China has adopted several national policies in an attempt to restructure and streamline its domestic coal industry (NDRC, 2007). Further, Chinese authorities have significantly lowered coal export quotas from 100 Mt in 2003 to less than 50 Mt in 2008 and introduced export taxes for coal during this period thus increasing its tight control over exports (NDRC, 2008).

Moreover, Indonesian steam coal production and exports have undergone a rapid expansion in recent years which was paralleled by political efforts to nationalize the mining industry. Indonesian steam coal exports jumped from 75 Mt in 2003 to an impressive 200 Mt in 2009 (IEA, 2010). This development indicates a switch in the Indonesian national resource policy away from oil exports to coal exports. Indonesia pulled out of OPEC in early 2009 in the eyes of diminishing oil stocks and production as well as strong domestic oil demand. Therefore, Indonesia may be currently promoting the strategy to become the dominant player in

[1] These developments have affected several OECD countries severely and have increased concerns about security of supply, as the major coal consuming nations depend heavily on imports of steam coal. Japan, South Korea and Taiwan import virtually all of their coals and Europe's average import dependency amounts up to more than 60%.

Asian coal markets to offset its declining oil revenues. The implementation of national resource policies in China and Indonesia have led to a structural shift of steam coal supply in the pacific basin in recent years. It may have given the authorities of either country the potential to exert market power on a national level.

This paper therefore analyzes the export patterns of major national players in the world steam coal market to identify if Indonesian and Chinese resource policies support the hypothesis of strategic market behavior on a national level. It is related to the empirical literature on strategic trade policy which has developed since the seminal papers of Brander and Spencer (1985) and Eaton and Grossman (1986) and others. Empirical literature on strategic trade in energy resource markets has so far been scarce. Many recent empirical contributions to this topic focus on international markets for agricultural goods and make use of diverse methods of analysis (see Reimer and Stiegert (2006) for an overview). Alston and Gray (2000) develop a simulation model to investigate wheat market conduct of the Canadian state trading enterprise. Dong et al. (2006) for instance find evidence for a quantity setting oligopoly to prevail in the international malting barley market using a menu approach. Using a calibration approach McCorriston and MacLaren (2010) assess the distorting impact of Chinese state trading enterprises on international agricultural markets.

We develop a static partial equilibrium model to test our hypothesis of non-competitive market behavior exercised through strategic trade policy in global steam coal trade. The model allows us to simulate perfect competition as well as non-competitive market structures where players act under a Cournot behavior assumption. We design the model as a mixed complementary program (MCP) by deriving the first order optimality conditions of the associated optimization problem. Modeling spatial equilibria in commodity markets has already been scrutinized since Samuelson (1952) who applied linear optimization techniques for competitive market structures. Takayama and Judge (1964) generalized spatial market economics for the non-linear case and multi-commodity markets and Harker (1986a) and Yang et al. (2002) developed conditions for various non-competitive spatial market equilibria. The application of such equilibrium modeling techniques to analyze market conduct is an active field of commodities research, e.g. in gas markets (Holz et al., 2008; Egging et al., 2010), in electricity markets (Müsgens, 2006; Lise and Hobbs, 2008) or in coking coal markets (Graham et al., 1999).

The literature on non-competitive market conduct of national players in international steam coal trade so far focuses on the maritime trade market which is a submarket of the global market and excludes domestic markets. Kolstad and Abbey (1984) were the first who applied a partial equilibrium model to analyze strategic behavior in seaborne steam coal trade in the early 1980s. The authors find that a non-competitive market structure consisting of a duopoly and a monopsony simulated the actual trade patterns well. However, since then the steam coal trade market has changed substantially. In a recent paper, Haftendorn and Holz (2010) analyze a number of major maritime coal trade routes and apply a mixed complementarity model to test if trade volumes on these routes fit competitive or oligopolistic behavior in the years 2005 and 2006. Their results suggest that the steam coal trade market is better represented by perfect competition in the analyzed periods. However, Trüby and Paulus (2011) model total trade market volume in an equilibrium approach and show that competitive models are unable to reproduce steam coal trade market equilibria in 2008.

Using our model, we test different hypotheses on market conduct and validate model results for the year 2008. In contrast to the majority of previous papers using equilibrium programming techniques, we validate our results applying a series of non-parametric tests such as the Wilcoxon-Sign-Rank test, Spearmann's rank correlation coefficient test as well as the Theil inequality coefficient. Our main finding is that perfect competition cannot explain market results, but a market structure setup with China and Indonesia acting as non-cooperative Cournot players fits observed trade flows and prices in 2008 best. Official Chinese steam coal export quotas in 2008 were consistent with simulated Chinese export volumes under a Cournot strategy.

Our paper extends the existing literature in two important ways: First, we account for interdependencies and feedbacks between domestic and international steam coal markets by explicitly modeling all relevant coal fields. Hence, we avoid strong assumptions on export potentials and extramarginal supply costs on the seaborne trade market. Second, we outline a rationale and provide empirical evidence for strategic trade policy on a national level to profitably influence steam coal market equilibria in 2008.

The remainder of the paper is structured as follows: in section 2 we outline what implications a trade market-only vs. a global market analysis yields and then focus on potentials for market power sources of several actors. We describe the model and data used in section 3. Main findings are presented in section 4. Section 5 concludes the paper.

2. Steam coal market economics

The majority of steam coals are not traded internationally but are produced and consumed in domestic markets. In 2008 total global hard coal production was 5850 Mt (IEA, 2010). The two largest domestic markets are China and the USA together comprising more than 65% of total production. About 13% of the global steam coal production is exported and traded internationally and more than 90% of international steam coal trade is seaborne.

The seaborne export market can be divided into a Pacific and an Atlantic market region[2]. Major importing regions in the Atlantic market are the USA and Europe (including neighboring Mediterranean countries) with the United Kingdom and Germany at the top. Traditionally these importing regions are primarily supplied by South Africa, Colombia and Russia.

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

In the export market two different types of suppliers interact with each other: Countries that have a dedicated export-oriented mining industry and countries with chiefly inland-oriented mining industries (Kopal, 2007; Bayer et al., 2009). The export-oriented countries primarily comprise South Africa, Colombia, Australia and Indonesia and holds most of the supply capacity. These export industries usually have a cost advantage over domestic industries due to good coal qualities, low mining costs and economical access to transport infrastructure. Countries with mainly inland oriented mining supply primarily are China, USA, India and Russia. These countries have some dedicated export collieries but a significant part of the mining capacity can serve both the national and the international market. However, interaction of dedicated export mines and domestic markets and and domestic mines with export markets is during most times limited: coal exporters often face a geographical disadvantage in supplying domestic markets as they are often located close to the coast within the vicinity of export terminals. Frequently, these export mines are also not well integrated into the domestic transportation railway system to allow for cost efficient movement of coals to domestic power plants. Vice versa, mines serving the domestic markets are often located deeper inland[3] and face high transport costs for moving coal to the export market. Furthermore, coal quality requirements differ significantly between the export and domestic markets, which means that coal upgrading, washing and drying could be necessary to bring domestic coals to export standards.

[2]From a market integration perspective the steam trade coal market can be considered well integrated (Li, 2008; Warell, 2006). Nevertheless, we use this labeling in a qualitative way in the scope of this paper to better structure our analysis of market actors.

[3]e.g. the Powder River Basin in the U.S., the coal bearing regions of Shaanxi and Inner Mongolia in China or several Russian coal production regions (Schiffer and Ritschel, 2007).

2.1. Market structure

Before we formally investigate non-competitive behavior in the steam coal market we informally discuss if there are indications that participants have actual potential to exercise market power. Market power potential may exist in the steam coal market in the sense of single large coal producing and exporting countries behaving in a non-competitive manner. This holds especially true for China and Indonesia.

China increasingly has made use of policy instruments, i.e. quotas and/or taxation, to tightly control participation of Chinese firms in the international trade market in recent years[4]. Firstly, political regulations require domestic mining companies to apply for special licenses which allow for a defined export volume. Quotas on steam coal are set and allocated by Chinese institutions in a yearly manner; nevertheless they may be subject to readjustments in case of political or economical requirements. E.g. the total export volume restriction for steam coal in 2007 was 70 Mt and has been reduced to 47.7 Mt in 2008 (NDRC, 2007, 2008). Secondly, the Chinese government levies export taxes on steam coal. In 2008 export taxes have been increased to 10% compared to no export tariff for steam coal in 2007 (TRCSC, 2008). These taxes significantly increased costs of Chinese coal on the trade market and thus may have had an additional impact on actual export volumes. Finally, political requirements in the coal industry consolidation process have added heavy restrictions on market entry which have strengthened the position of a few very large state-controlled coal companies (Sun and Xu, 2009).

While indications for market power executed on a nation-wide level are less obvious in Indonesia, there exists a mine ownership structure which is quite special: mining rights have been awarded mostly to international mining companies in the early eighties. However, foreign investors were obliged to offer at least fifty one percent of shares to Indonesian companies or the government after ten years of mine production (Baruya, 2009). Mining rights awarded in the nineties and later went exclusively to Indonesian companies. This lead to the current situation, where the majority of steam coal mine production facilities in Indonesia are owned by large Indonesian consortia[5] or the government. The government is also actively controlling export volumes to decrease speed of reserve exploitation as well as to cover rapidly growing domestic demand (Kuo, 2008). An additional aspect is Indonesia's geography: a large amount of steam coal can be shipped by barges via the navigable rivers of Kalimantan to offshore loading terminals or directly to Thailand or South China (Schiffer and Ritschel, 2007). This means that Indonesian export infrastructure is practically not capacity constrained, which may have allowed Indonesia to export higher volumes than it actually did

[4]Similar government policies on various raw materials are documented by Hurst (2010).

[5]One example is PT BUMI Resources which owns the mining companies PT Arutmin and PT Kaltim Prima Coal which together accounted for 54 million tonnes or 32% of Indonesian steam coal exports in 2007.

in 2008. One possible explanation could be that Indonesia actively pursued to limit exports in order to keep international market prices at a higher level.

The exertion of market power may be supported by important barriers to entry and capacity expansion restrictions in the steam coal market. Firstly, high political risk and/or the lack of financial resources and technical capability are effective barriers against the market entry of developing countries with so far untapped high quality coal fields like Botswana, Zimbabwe and Madagascar. Secondly, export capacity expansion usually requires coordination of infrastructure and mining capacity upgrading with different stakeholders being involved. This process can be very slowly as the example of South Africa shows, where mining companies upgraded production and export terminal facilities but national railway expansion still lags behind. Such restrictions are particularly delaying for greenfield projects which need access to transport infrastructure.

2.2. Implications of an export market analysis vs. an integrated analysis of export and domestic markets

In the case of the coal market, previous literature has so far focused on testing for non-competitive behavior in the export market. Even though interaction between domestic supply and dedicated export supply is sometimes hampered by transport costs, limited transport capacity or coal quality, we argue that interaction between domestic markets and international trade does exist [6]. In the following, we consider that a national player is an entity which maximizes welfare in its domestic market plus its producer rent from sales to the export market less costs.

Proposition. *If the export market price is sufficiently high, and dedicated export capacities are constrained, then dedicated domestic production will enter the global market even if it has a cost disadvantage.*

Proof: see Appendix.

Intuitively, domestic supply will enter the export market if marginal cost (including the cost disadvantage of domestic production) equal marginal export revenues. If we consider that the national player acts competitively, the marginal export revenue is equal to export market prices. In this case a setup only taking into account the trade market will be rendered inconsistent if export prices just rise high enough. If the national player pursues a non-competitive strategy (e.g. á la Cournot), the same holds true. However, export market prices have to be higher as in this case the national player will account for the price reduction

[6]This is especially true for some of the large domestic markets like China and the U.S. Historically, both countries have adjusted their export volume depending on the difference between the export market price and domestic market prices. Further, transport infrastructure for domestic mines did not seem to be a bottleneck in 2008: Chinese coal exports peaked in 2005 with exports of approximately 80 Mt. U.S. coal exports were around 100 Mt in the early 1990s. Therefore, coal exports in 2008 of 54 Mt in the case of China and 74 Mt in the case of the U.S. where most probably not constrained by transport capacity.

inferred by supplying additional volumes to the export market. If we look at real coal prices in the export market, and thus marginal revenues, it can be observed that they were particularly high in 2008 (IEA, 2010) which makes an interaction of domestic supply and export markets quite likely.

Based on the information about the current market structure we define three hypotheses for our investigation of potential non-competitive behavior in the steam coal trade market:

H1: steam coal market results in 2008 correspond to a perfectly competitive market setting.

H2: Indonesia acts as a strategic national player in the steam coal export market besides a competitive fringe of other producers.

H3: China and Indonesia both act as non-cooperative strategic national players in the steam export coal market besides a competitive fringe.

In the following, we will develop a large-scale empirical model to verify which hypotheses we can reject.

3. The model

In this section, we develop the model and describe the data we used. We will also outline our market structure scenarios and depict statistical methods we will use to compare model results with actual data.

The model is structured to find the spatial equilibrium of prices and trade flows between a given set of players given assumptions about their conduct and objective functions. We model three types of players: national producers which maximize their producer rents from sales to the export market in a Cournot fashion and at the same time maximizing overall welfare in their domestic coal markets (strategic players); producers which act in a competitive manner as price takers on the export market and also as welfare maximizers in their domestic coal markets (competitive fringe); and demand regions without significant coal production which act as price takers. All producers maximize profits subject to a number of capacity constraints and energy balance equations[7].

As demonstrated by Salant (1982); Kolstad and Burris (1986) and recently by Lise and Krusemann (2008) and by Montero and Guzman (2010), different types of Cournot games can be mapped by a term which is a producer's conjecture about the response of other producers to a change in their production volume. This term can be inserted in the producers pricing equation to reflect that player's degree of market power.

[7]We model energy flows which accounts for consumers buying energy, not mass. All capacities and cost functions for production and transport are normalized to a standard coal energy content in each mining region. This methodology has already been used by Paulus and Trüby (2010). For the sake of simplicity we suppress the energy-mass parameters in the model formulation.

This term can be viewed as oligopolistic rent of the producer trading at a price above his marginal costs of supply.

3.1. Model statement

The model contains a topology of nodes $n \in N$. All nodes can be subdivided into mining regions $m \in M$, export terminals $e \in E$ and demand regions $d \in D$ so that $N = M \cup D \cup E$. The roles of nodes are mutually exclusive $M \cap D = \emptyset$, $M \cap E = \emptyset$ and $D \cap E = \emptyset$. Further there exists a set of players $p \in P$. In our model, players are nations with significant steam coal production. Players $p \in P$ control mining regions $m \in M_p$, export terminals $e \in E_p$ as well as demand regions $d \in D_p$. Mining regions can only be controlled by one player $M_p \cap M_{p'} = \emptyset, \; \forall \, p \neq p', \; p, p' \in P$. This relation also holds true for export terminals $E_p \cap E_{p'} = \emptyset, \; \forall \, p \neq p', \; p, p' \in P$. Nodes are connected through transport arcs $(i, j) \in A \subset N \times N$. Sets, parameters and variables of the model are found in the appendix in Table 3, Table 4 and Table 5 respectively.

The remainder of this section is organized as follows: We first develop the optimization problem, then we state the corresponding first-order optimality conditions solved by each player type. The first-order conditions together with the market-clearing conditions define the Nash-Cournot game for the worldwide steam coal market.

The variables in parentheses on the right hand side of each constraint are the Lagrange multipliers used when developing the first-order conditions. The complementary slackness condition is indicated by a $\perp$ sign, where $0 = x \perp y = 0 \Leftrightarrow x^t y = 0$ for vectors x and y.

Profit maximization of producers

Player $p \in P$ maximizes his pay-off which is defined as producer rent from the export market plus overall welfare from domestic coal markets minus costs for production, shipping and turnover. The pay-off function $PO_p(z_p) : \mathbb{R}^{|M_p|+|A|+|D|} \mapsto \mathbb{R}$ and the corresponding decision vector z_p can then be written as:

$$
\begin{aligned}
\max_{z_p \in \Omega_p} PO_p(z_p) = & \sum_{d \in D_p^-} v_d \left(X_d^- + x_d^p \right) x_d^p + \sum_{d \in D_p} \int_0^{X_d} v_d(u) \mathrm{d}u \\
& - \sum_{m \in M_p} C_m^p(s_m^p) - \sum_{(n,n') \in A} q_{(n,n')}^p c_{(n,n')}^T - \sum_{(e,n') \in A} q_{(e,n')}^p c_e^E, \qquad (1)
\end{aligned}
$$

with $X_d^- = \sum_{p' \in P^-} x_d^{p'}$. PO_p is continuously differentiable and concave in the case that C_m^p and v_d are continuously differentiable and C_m^p is convex and v_d is concave. Profit maximization for every producer $p \in P$ is constrained by a set of restrictions for transport and production capacities (dual variables in parentheses):

$$Cap_m^M - s_m^p \geq 0, \qquad (\mu_m^p) \qquad \forall p \in P,\ m \in M_p, \tag{2}$$

$$Cap_e^E - \sum_{(e,n)\in A} q_{(n,n')}^p \geq 0, \qquad (\epsilon_e^p) \qquad \forall p \in P,\ e \in E_p, \tag{3}$$

$$Cap_{(n,n')}^T - \sum_{p'\in P} q_{(n,n')}^{p'} \geq 0, \qquad (\phi_{(n,n')}) \qquad \forall p \in P,\ (n,n') \in A. \tag{4}$$

Our model incorporates a complex network topology which allows for routing of sales volumes along different paths and several nodes, we use the notion of path variables $q_{(n,n')}^p$ (Harker, 1986b). This concept allows us to map trade flows from mines to demand regions along several intermediary nodes.

Energy balance equations have to hold for mining regions $m \in M_p$:

$$s_m^p + \sum_{(n,m)\in A} q_{(n,m)}^p = \sum_{(m,n)\in A} q_{(m,n)}^p \qquad (\lambda_m^p) \qquad \forall p \in P,\ m \in M_p, \tag{5}$$

for export regions $e \in E_p$:

$$\sum_{(n,e)\in A} q_{(n,e)}^p = \sum_{(e,n)\in A} q_{(e,n)}^p \qquad (\lambda_e^p) \qquad \forall p \in P,\ e \in E_p, \tag{6}$$

and for demand regions $d \in D$:

$$\sum_{(n,d)\in A} q_{(n,d)}^p = x_d^p + \sum_{(e,n)\in A} q_{(e,n)}^p \qquad (\lambda_d^p) \qquad \forall p \in P,\ d \in D. \tag{7}$$

The objective function (1) and equations (2) to (7) define the maximization problem Ω_p. In case that the objective function P_p is concave and all depicted constraints are convex and all functions are continuously differentiable, the formulated optimization problem can be represented by its first order optimality conditions. In this case, the first order derivatives constitute necessary and sufficient equilibrium conditions.

Producer optimality conditions

We develop the Lagrangian $\mathcal{L}$ of the original problem Ω_p. In the following, we derive the first order optimality conditions from $\mathcal{L}$. The first order partial derivative w.r.t. export volumes x_d^p between player $p \in P$ and $d \in D^-$ is given by

$$v_d(X_d) - \left(\lambda_d^p - \left(\frac{\partial v_d}{\partial x_d^p} + \frac{\partial v_d}{\partial X_d^-}\frac{\partial X_d^-}{\partial x_d^p}\right) x_d^p\right) t^{p\to d} \geq 0 \perp x_d^p \geq 0, \qquad \forall d \in D^-. \tag{8}$$

The first term is the price in node d, the second term gives the marginal cost of supply of player p to node d. The third term is the Cournot markup depending on the marginal change of consumer price if player p changes x_d^p marginally. We adjust prices by value added tax differences and royalties between different model regions by multiplying export prices with the term $t^{p \to d}$. In equilibrium, if $x_d^p \geq 0$, the achieved price of exports p_d has to offset marginal costs of supply to node d and the marginal price decrease caused by this export flow in d.

The Cournot player perceives that the demand function in d is downward sloping and thus can extract an oligopolistic producer rent. His sales decision for d also depends on his perception on how sales of competitors for d change, given a change in his sales:

$$\frac{\partial v_d}{\partial x_d^p} + \frac{\partial v_d}{\partial X_d^-} \frac{\partial X_d^-}{\partial x_d^p} = \frac{\partial v_d}{\partial x_d^p}(1 + r^{p \to d}). \tag{9}$$

$\frac{\partial v_d}{\partial x_d^p} = r^{p \to d}$ is the aggregate conjecture of player p on how export flows from all other players $p^* \in P^-$ change given a change in its own export trade volume to demand region d. For perfect competition, $r^{p \to d}$ equals -1 and for a Cournot-Nash equilibrium this term equals 0[8].

P behaves as a welfare maximizer in his domestic national markets. First-order pricing conditions for P's supply x_d^p in domestic markets $d \in D_p$ are defined as:

$$v_d(X_d) - \lambda_d^p \geq 0 \perp x_d^p \geq 0, \qquad \forall d \in D_p, \tag{10}$$

which means that P is behaving as a price taker in its domestic markets.

Single mining regions are assumed to behave competitively, supplying at marginal cost levels plus scarcity rents for congested mining capacity

$$\frac{\partial C_m^p(s_m^p)}{\partial s_m^p} + \mu_m^p - \lambda_m^p \geq 0 \perp s_m^p \geq 0, \qquad \forall m \in M_p. \tag{11}$$

For the mine production cost C_m^p, we choose a function of production volume s_m^p according to Golombek and Gjelsvik (1995). In their paper the authors present a production cost function, for which the marginal supply cost curve has an intercept $\alpha_m \geq 0$, then follows a linear trend with slope $\beta_m \geq 0$ until production reaches almost the capacity limit. As soon as the supply level approaches production capacity limits the marginal costs can increase exponentially depending on a parameter $\gamma_m \leq 0$. The economic intuition behind this functional form for marginal costs is that prices during periods with higher demand are in reality often

[8] Kolstad and Burris (1986) for example elaborate more on this topic. Such games were applied in equilibrium energy market modeling e.g. by Graham et al. (1999), Chen et al. (2006) or Lise and Krusemann (2008).

set by older mine deposits. As geological conditions decline, these mines face significantly higher costs and have to reduce their production output due to geological constraints and limited reserves. These high-cost mine fields serve as spare capacity during demand peaks and reduce their output if demand declines.

The strictly convex and continuously differentiable marginal supply cost function $\frac{\partial C^p_m(s^p_m)}{\partial s^p_m} = c^p_m : [0, Cap^M_m) \mapsto \mathbb{R}^+$ for player $p \in P$ and mine $m \in M_p$ is defined as:

$$c^p_m(s^p_m) = \alpha_m + \beta_m s^p_m + \gamma_m \ln\left(\frac{Cap^M_m - s^p_m}{Cap^M_m}\right), \qquad \alpha_m, \beta_m \geq 0,\ \gamma_m \leq 0. \tag{12}$$

Price efficiency conditions have to hold for every transport connection $(n, n') \in A$. For transport connections going out from mining regions $m \in M$ and from demand regions $d \in D$ price efficiency is that marginal costs of supply λ^p_n and $\lambda^p_{n'}$ only differ by transport costs and a possible markup for scarcity rents in the case of congested transport capacity $\phi_{(n,n')}$ if $q^p_{(n,n')} \geq 0$.

$$\lambda^p_n + c^T_{(n,n')} + \phi_{(n,n')} - \lambda^p_{n'} \geq 0 \perp q^p_{(n,n')} \geq 0, \qquad \forall n, n' \in M_p \cup D \ \wedge \ (n, n') \in A. \tag{13}$$

similar conditions hold for transport connections going out from export terminals but include an additional scarcity markup variable for congested export terminal capacity ϵ^p_e,

$$\lambda^p_e + c^T_{(e,n)} + \phi_{(e,n)} + \epsilon^p_e - \lambda^p_n \geq 0 \perp q^p_{(e,n)} \geq 0, \qquad \forall e \in E_p,\ \wedge (e, n) \in A. \tag{14}$$

Market clearing conditions

In addition to the derived first order optimality conditions we assume that there is no market power on the demand side and that all markets in demand regions $d \in D$ are cleared when players have decided on their strategies. We choose a linear, strictly decreasing demand function $v_d(X_d) : \mathbb{R}^+ \mapsto \mathbb{R}^+$ of the form $v_d = a_d + b_d X_d$. The slope b_d is defined as $b_d = \frac{v^{ref}_d}{X^{ref}_d} \frac{1}{\sigma_d}$, and the intercept a_d can be written as $a_d = v^{ref}_d - b_d X^{ref}_d$, where σ_d, v^{ref}_d and X^{ref}_d are the demand elasticity, reference price and total reference consumption in demand region d, respectively. This leads to the following inverse demand function:

$$v_d = v^{ref}_d + \frac{1}{\sigma_d}\left(\frac{\sum_{p' \in P} x^{p'}_d}{X^{ref}_d} - 1\right), \qquad v_d\ (free) \qquad \forall d \in D. \tag{15}$$

We can now calculate:

$$\frac{\partial v_d}{\partial x^p_d} = \frac{p^{ref}_d}{X^{ref}_d} \frac{1}{\sigma_d} = b_d. \tag{16}$$

Inserting (16) into the profit maximization condition (8) yields to:

$$v_d(X_d) - \left(\lambda_d^p - \frac{p_d^{ref}}{X_d^{ref}}\frac{1}{\sigma_d}(1 + r^{p\to d})x_d^p\right)t^{p\to d} \geq 0 \perp x_d^p \geq 0 \qquad \forall d \in D. \tag{17}$$

If we bundle the equations (15) with the first order conditions (17), (11), (13), (14) and capacity constrains (2) to (7) for all producers $p \in P$, the unique solution to this set of (non)linear inequalities yields the equilibrium for the market. The resulting system of inequalities is known as a mixed complementarity problem. This problem is implemented in GAMS and is solved using the PATH solver (Ferris and Munson, 1998).

3.2. Model parametrization

Our assumptions on reference volumes, and for price elasticities of coal demand in Europe are explained in detail in Trüby and Paulus (2011)[9]. Demand elasticities for other regions are based on a broad literature review of econometric analyses on inter-fuel substitution. While methodological approaches as well as the age of the reviewed articles differ, all authors agree that price elasticity of steam coal demand is inelastic $\mid \sigma \mid < 1$. In this paper, we assume a price elasticity of steam coal demand for -0.3 for the other world regions beside Europe.

Information on costs and capacities in the steam coal market is only available from a multitude of heterogeneous sources. We use an extensive steam coal market database in this analysis that has already been presented and used in one of our former analyses (Paulus and Trüby, 2010) and Trüby and Paulus (2011)[10].

We consider it crucial to capture not only isolated steam coal trade market economics but also the inter-dependencies between the large domestic markets and the trade market. Therefore, we have implemented a detailed network topology consisting of several dozen mining regions, export terminals and demand regions (see Table 1). Note that our model includes the two largest domestic markets, China and the US, which together accounted for 65% of global hard coal production and 66% of global consumption. Other major

[9] In this article, we use existing large-scale power sector dispatch models for Europe and iteratively test a high number of steam coal price points. The model returns a minimum cost power plant dispatch as well as steam coal consumption. The results show that the steam coal demand elasticity in the European power sector was relatively low, -0.43 in 2008.

[10] Relevant publications on steam coal markets are available from public institutions like the IEA (2009) or the EIA (2007, 2010a,b). Comprehensive information is especially obtained from the published reports of the IEA Clean Coal Center, e.g.: Baruya (2007, 2009); Minchener (2004, 2007) and Crocker and Kowalchuk (2008). Furthermore, Ritschel (2010) and Schiffer and Ritschel (2007) depict recent developments in the hard coal markets. Further publications include analyses from employees working for international utilities as for example Bayer et al. (2009) and Kopal (2007). Industry yearbooks provide useful information as it is the case for China (NBS, 2008; CCII, 2007). National statistics bureaus and mineral ministries provide high quality information as for example ABARE (2008) and ABS (2006). Not mentioned are a larger number of coal company annual reports as well as information based on expert interviews. Information on average energy content is based on Ritschel (2009); IEA (2009) and BGR (2008). For Australia, ABS (2006) delivers detailed information, Baruya (2007) compares different mining input factor structures on the global scale. Furthermore, our analysis is based on several extensive research projects of Trüby and Paulus (2010) and Eichmüller (2010) at the Institute of Energy Economics at the University of Cologne.

domestic markets are Russia and India which have also been taken into account.

Table 1: Model topology

Mining regions & export terminals[a]		Demand regions	
Australia	5	**Russia**	4
South Africa	3	**U.S.**	7
Indonesia	2	**China**	8
Russia	8	**India**	3
Colombia	2	**Poland**	2
Venezuela	2	Europe	3
Vietnam	2	Japan	1
U.S.	6	Korea (S.)	1
China	10	Taiwan	1
India	6	Asia, other	1
Poland	3		

[a]bold faced entries are countries with large domestic steam coal markets which have been explicitly modeled.

3.3. Market structure scenarios

We simulate the global steam coal market trade for 2008 under four different assumptions on market conduct and the nature of Chinese export quotas to test our hypotheses:

Perfect competition without Chinese export quota: This scenario assumes that all producers and consumers act in a competitive manner. We further assume no Chinese export quotas in this scenario to assess how unconstrained Chinese export patterns would have looked like and how they would have influenced the steam coal market.

Perfect competition with Chinese export quota: This scenario also assumes perfectly competitive behavior of market players but incorporates the Chinese export quota as a fixed export restriction. Thus, we assume that the export quota was not necessarily set under strategic welfare maximization objectives, but could exist due to other political objectives like the conservation of domestic resources. With this scenario, we may test for the competitiveness of the global steam coal market.

Indonesian monopoly with Chinese export quota: In this scenario we assume that Indonesia, the largest exporter acts as a strategic national player besides a competitive fringe of other market players. The Chinese export quota is modeled as a fixed export restriction for the Chinese player. This scenario lets us test for non-competitive behavior of Indonesia.

China - Indonesia duopoly: Besides their large market shares, Indonesia and China face special political, geographical and institutional characteristics which could potentially support non-competitive behavior. We therefore model both countries as non-cooperative strategic players. With this scenario we may investigate if Chinese export quota setting is consistent with a profit maximizing Cournot strategy, together with Indonesian market power.

3.4. Model validation using statistical tests

We assess the forecasting abilities of the model by comparing trade flows as well as trade flow shares as a fraction of total trade with the actual values in 2008. We also validate model prices with real price data.

In order to validate which of the market conduct scenarios fits the observed data best, we employ a series of statistical techniques. Using common parametric tests in such a setup would lead to the violation of several assumptions, most importantly, that the error term is normally distributed. Alternatively, it is possible to use non-parametric tests, which do not make the same assumptions on distributions. We use two non-parametric tests to validate our results: the Wilcoxon-Rank-Sign test and Spearman's rank correlation coefficient test.

The Wilcoxon-Sign-Rank test evaluates on the basis of a paired sample the signed-rank correlation between the sets (Wilcoxon, 1945). We employ this test on the modeled trade flow share matrix M and the observed trade flow share matrix O. (m_{pd}, o_{pd}) are the corresponding modeled and observed trade flow shares for all $p \in P$ and $d \in D$. The null hypothesis is that the model results predict actual trade.

An alternative test, which is also distribution free is Spearman's rank correlation coefficient test. Similar to Abbey and Kolstad (1983) and Graham et al. (1999) we try to find if the observed trade shares and the error between predicted and observed values has no rank-correlation, which would indicate that there is no association between the error terms and the actual values. The regression of the observed values o_{pd} against the predicted values m_{pd} yields the regression equation:

$$o_{pd} = \alpha + \beta m_{pd} + \hat{u}_{pd}, \qquad \forall p \in P,\ d \in D$$

If our model would perfectly simulate each trade flow share, then $\beta = 1$ and $\alpha = 0$. To test for these parameter values, we let $\hat{u}_{pd} = o_{pd} - m_{pd}$ and test the extend of rank correlation between o_{pd} and $\hat{u}_{pd}$ by applying Spearman's rank correlation coefficient. The null hypothesis is that there is no correlation between observed values and the error term between modeled and actual values or, equivalently, that the model predicts the observed market outcome.

Furthermore, we also employ statistics without testing for interference: the Theil inequality coefficient is the root mean squared error of two datasets scaled to the $[0, 1]$ interval (Theil, 1966). It measures how distant both datasets are from each other in a statistical sense. In case of the Theil coefficient equaling zero, the modeled trade shares are exactly the same as the actual ones. Therefore, the lower the Theil coefficient, the better the model suites as an indicator for the real market. Further information can be obtained by calculating the covariance proportion, the variance proportion and the bias proportion of the mean squared error (MSE). A good quality forecast should have a MSE which is mostly explained by the unsystematic error. In this case, the bias and the variance proportion should be close to zero and the covariance proportion close to one.

4. Results

Table 2 reports results on statistical inference, as well as on several other statistics in the four simulated scenarios. Both perfect competition assumptions are rejected by the Wilcoxon Sign-Rank test on the 90% confidence level (95% level in the scenario without export quota). Both non-competitive scenarios cannot be rejected at typical confidence levels. The Spearman rank correlation test rejects the two perfect competition scenarios as statistically significant estimators for the actual market outcome on the 95% level. Again both non-comeptitive scenarios cannot be rejected at typical confidence levels.

The other statistics further confirm the non-competitive setups: the Theil inequality coefficient as well as the RMSPE are far lower than in the perfect competition scenarios. However, for both statistics the China - Indonesia duopoly scenario even outperforms the Indonesia monopoly scenario. The values for covariance proportion and for the variance proportion are also the best in the China - Indonesia duopoly setup. The bias proportion is the lowest (best) in the perfect competition with export quota scenario, nevertheless, the bias proportion is also relatively low in the China - Indonesia duopoly scenario with 2%.

The international seaborne trade market size is an endogenous variable to the model as we account for interactions of the trade market with the domestic markets. We therefore compare how good the model results for the total trade market volume fit the actual figures. In the perfect competition scenario without export quota, the simulated trade market volume is 20% larger than the actual market size in 2008. In this scenario, Indonesia and especially China significantly increase their exports to cover the high international demand in the year 2008. This leads to a drastic increase in traded steam coal volumes in the pacific area. In the perfect competition scenario with export quota, Chinese export volumes are constrained which leads to a lower overall trade market volume. The China - Indonesia duopoly setting sees the best market volume fit with the trade market being only 4% larger than in reality. China as the largest producer and Indonesia as the largest trade market exporter withhold volumes in a Cournot manner. Under the Cournot assumption, simulated Chinese exports (43.3 Mt) almost exactly meet the export quota (47.8 Mt). This

Table 2: Comparison of statistics of actual and modeled treade flows in 2008

Test statistics[a]	Market structure				Actual market
	PC w/o export quota	PC w. export quota	Indonesia monopoly w. export quota	China - Indonesia duopoly w/o export quota	
$\rho_{Spearman}$	0.328**	0.259**	0.186	0.162	
$z_{Wilcoxon}$	2.53**	1.80*	1.17	0.62	
Theil	0.42	0.352	0.214	**0.152**	
Error term decomposition:					
-Covariance proportion	0.934	0.848	0.835	**0.935**	
-Variance proportion	0.078	0.165	0.174	**0.063**	
- Bias proportion	0.002	**0.002**	0.007	0.018	
RMSPE [%]	23.5	16.9	11.6	**7.9**	
Results on market size in Mt					
Total trade volume	732	659	645	**628**	608

[a] $\rho_{Spearman}$ is the Spearman rank correlation coefficient, $z_{Wilcoxon}$ is the statistic for the Wilcoxon sign rank test, Theil is the Theil inequality coefficient and U^c is its covariance proportion. Bold case indicates the lowest Theil statistic or that the covariance (variance,bias) proportion is closest to one (closest to zero). The same holds for the root mean-squared percentage error (RMSPE). The null hypothesis for both tests is that the model can predict trade in 2008. *Significant on the 90% level. Critical values: $\rho_{Spearman}$=0.213 and $|\ z_{Wilcoxon}\ |$=1.650.
**Significant on the 95% level. Critical values: $\rho_{Spearman}$=0.253 and $|\ z_{Wilcoxon}\ |$=1.960.
***Significant to the 99% level. Critical values: $\rho_{Spearman}$=0.329 and $|\ z_{Wilcoxon}\ |$=2.576.
Critical values are based on Zar (1972) and McCornack (1965).

means that the Chinese export policy was consistent with a Cournot-Nash strategy[11] in 2008. Additionally, the Cournot competition leads to a diversification of Chinese exports similar to reality with Japan, South Korea and Taiwan being the main destinations[12], in all scenarios where China acts competitively, China exports exclusively to South Korea.

A similar observation can be made for Indonesia: Indonesian supply is similarly diversified as actual values in both non-competitive scenarios. In the China - Indonesia duopoly scenario, simulated Indonesian exports (160.4 Mt) almost match actual values (157.4 Mt, energy-adjusted). This is in contrast to the perfect competition scenarios, where Indonesia's absolute exports are more than 30 million tonnes higher. Also, in the competitive scenarios exports from Indonesia to China are strikingly higher than in reality. In general, the China - Indonesia duopoly setup clearly outperforms both perfect competition scenarios. The China - Indonesia duopoly setup also performs better than the Indonesia monopoly with export quota scenario in all statistics but the bias proportion. However, both non-competitive scenarios cannot be rejected as predictors of actual market outcome.

A further relevant indicator to analyze model forecasting quality are prices. The RMSPE for the perfect competition scenario without export quota (with export quota) is 21.7% (18.7%). For the Indonesia monopoly with export quota scenario the RMSPE is 4% and for the China -Indonesia duopoly scenario 3.6%. Figure 1 plots actual against simulated prices. We observe that prices in the perfect competition setups are approximately 15-20 USD/t lower in Europe and up to 40 USD/t lower in the main Asian importing regions than observed prices. Simulated import prices in China are higher than in reality. Furthermore, we see that prices between both perfect competition scenarios do not differ greatly, even though Chinese exports are 70 Mt lower as Indonesia is still exporting above its observed values.

Model prices for both non-competitive scenarios fit the observed values better. While simulated import prices meet the actual European price levels, this scenario also fairly accurately replicates actual prices in the Asian import regions. The best price fit for China has the China - Indonesia duopoly scenario: here, the Cournot mark-up of Chinese exports leads to a larger price delta between other Asian import regions and Chinese domestic demand regions which basically protects the Chinese coal market and reduces coal consumer prices.

[11] Of course this does not necessarily mean that China is a strategic player.

[12] Trade flows are more diversified in the non-competitive equilibrium compared to the perfectly competitive market outcome. In the Cournot game firms with higher marginal costs of delivery (e.g. due to high transport costs to distant demand regions) have lower market shares in the respective demand regions. Lower market shares however imply higher perceived marginal revenues for a player. Since the Cournot oligopolists equate marginal revenues to marginal costs, the higher perceived marginal revenue may justify trade with regions that would cost-wise not occur in a perfectly competitive market. For a more sophisticated analysis of this issue e.g. refer to Brandner (1981) and Brander and Krugman (1983)

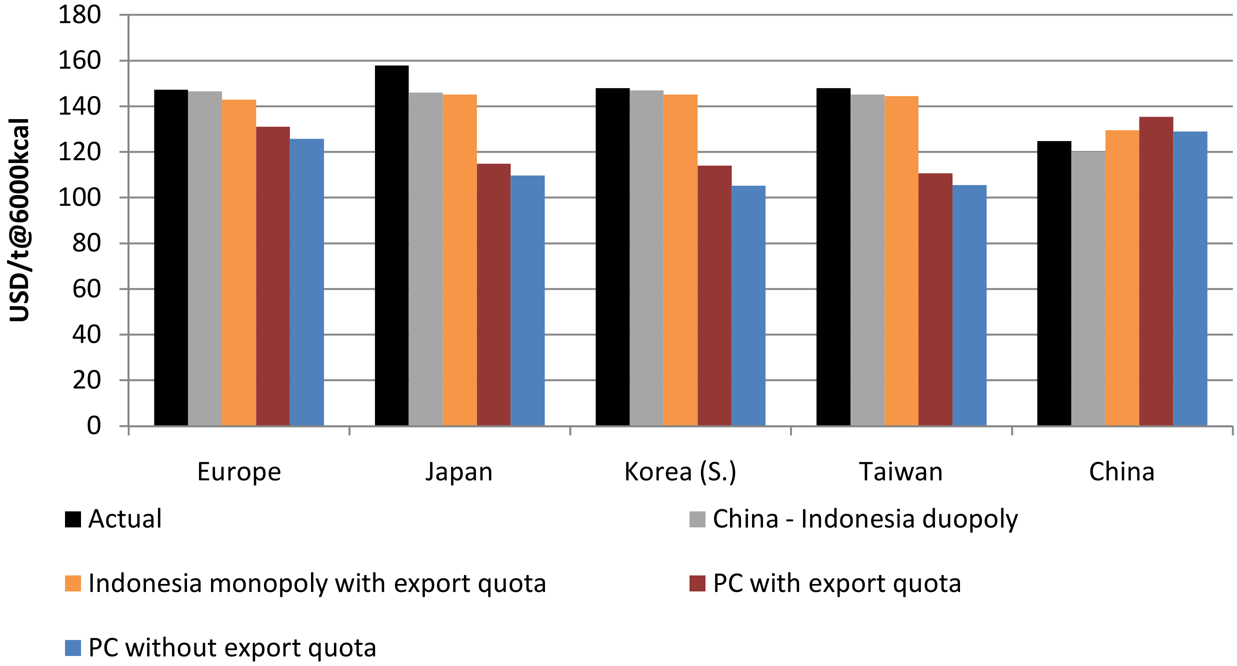

Figure 1: Comparison of actual and simulated prices for important import regions

Simulated Japanese import prices may not be completely explained even in the China-Indonesia setup[13]. Besides these deviations, both non-competitive scenarios deliver the most accurate reproduction of actual import prices.

Considering the actual and simulated trade flow matrices, the perfect competition setups feature a less diversified structure of supply than the non-competitive scenarios (see Table 6 in the appendix).

4.1. Costs of non-competitive behavior

As it is known from economic theory, perfect competition (c.p.) leads to the highest overall welfare compared to a scenario with non-competitive market behavior. The baseline in Figure 2 is therefore the perfect competition scenario without Chinese export constraints.

In the perfect competition scenario with Chinese export quota, China accrues less welfare due to its export restriction. Indonesian rents increase to a certain extend due to slightly higher world market prices. In the Indonesia monopoly scenario, Indonesian rents increase by around 3 bn $ as the withholding of Indonesian

[13]Besides statistical errors and differences in energy-mass conversions, coal quality is a factor which may let model results deviate from real trade patterns. Especially in Japan, newer coal fired power plants are highly efficient but very limited in the types of steam coal that they may use for generation. Coal specifications on sulfur, ash content, moisture and volatile matter are important determinants for coal-fired power plants. This dependence may sometimes lead to a certain price inelasticity of demand for certain coal types. Trade patterns and price effects caused by coal quality requirements beyond energy content are not explicitly modeled and beyond the scope of this analysis.

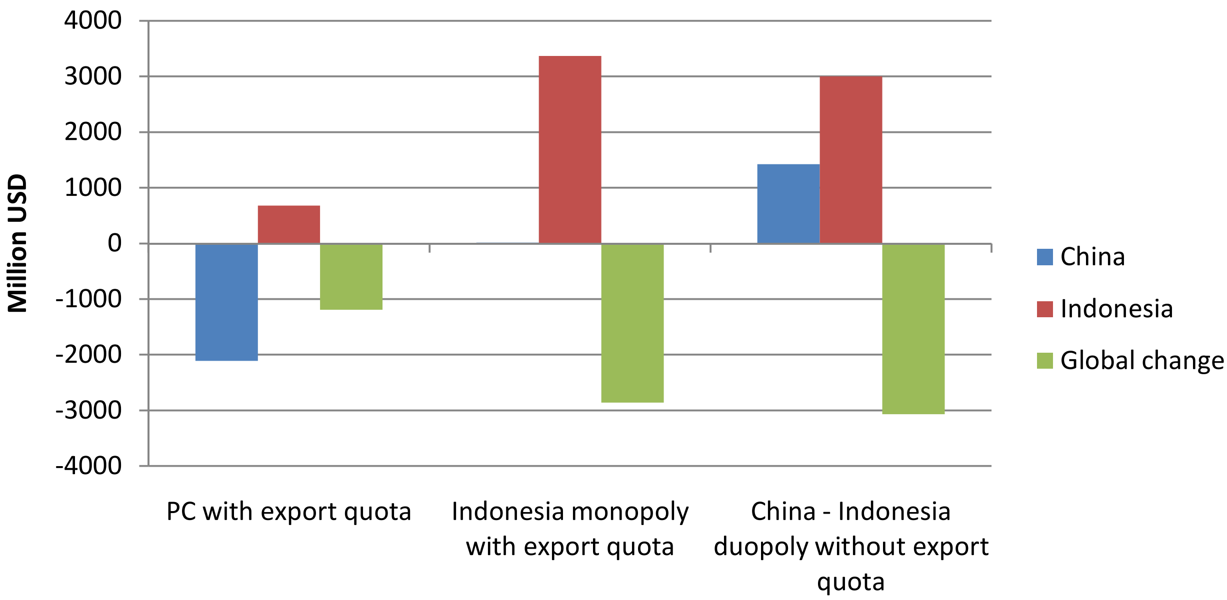

Figure 2: Welfare effects in the investigated scenarios (horizontal lines represents the perfect competition scenario without export quota).

supply on top of the Chinese export quota increases consumer prices significantly. In this scenario, Chinese welfare effects are close to zero, as positive revenue effects due to higher consumer Asian prices and negative effects due to the export quota compensate each other. Overall global welfare effects are negative due to lower consumer rents especially in the main Asian importing nations of Japan, Taiwan, and South-Korea but also in Europe.

In the China - Indonesia duopoly setup, China accrues additional rents[14] of 1.4 bn USD while oligopolistic rents of Indonesia decrease slightly. Chinese rents increase as exports are distributed with regard to profit maximization targets. This leads to a broader (and more realistic) diversification of Chinese export flows compared to the scenarios where China acts as a competitive player. Consumer prices for steam coal in China are slightly lower compared to the Indonesia monopoly scenario, which positively affects Chinese consumer rents.

Summarizing our findings, we conclude that hypothesis H1 (perfect competition) can be clearly rejected as prices and trade flow patterns cannot explain the real market outcome. Both non-competitive scenarios cannot be rejected as predictors of actual trade. Indonesian and Chinese exports are more accurately distributed compared to their counterparts in the perfect competition setup. Furthermore, total Indonesian export volumes fit better in the non-competitive setups. Of the two non-competitive setups, the China -

[14]We also account for welfare changes in the domestic Chinese steam coal market.

Indonesia duopoly scenario performs slightly better in several statistics, trade flows and prices. Interestingly, the Cournot-Nash strategy for China reproduces almost exactly the Chinese export quota. Additionally, positive welfare effects for China are the highest in this setup.

Therefore, we cannot reject both H2 (Indonesian monopoly with Chinese export quota) and H3 (China - Indonesia duopoly). However, the China - Indonesia duopoly outperforms the Indonesia monopoly scenario in seven of the eight statistics we computed (see Table 2). The duopoly scenario also shows the highest welfare accruement for China. In the background of the general proactive national energy resource security policy in China, one may therefore even support the acceptance of H3.

5. Conclusions

Due to the increasing demand for mineral resources in recent years, several resource-rich nations have reassessed and adjusted their national resource policies. They have applied different instruments of strategic trade policy such as export quotas and taxes. However, it may not always be clear if these resource policies serve conservation of natural resources or maximization of national rent inflows from resource exports. We empirically investigated this question for the case of the global steam coal market by testing for non-competitive market conduct of China and Indonesia. Both countries have implemented or significantly realigned their coal export strategies in recent years.

For this purpose, we developed a partial equilibrium model which allowed us to model individual nations as strategic players, maximizing their domestic welfare as well as their rents from exports subject to a Cournot-Nash strategy. We described how China and Indonesia could potentially exercise market power in reality and derived two non-competitive market conduct setups from this investigation. We applied several statistical tests to avoid arbitrary modeling results. Therefore, we come to the conclusion that we cannot reject two non-competitive market setups as predictors of the actual steam coal market in 2008. Test statistics indicate that the China - Indonesia duopoly scenario is the better predictor than the Indonesia monopoly scenario. We also found that Chinese export quotas are consistent with simulated Chinese export volumes under a Cournot-Nash strategy which gives further strength to our hypothesis regarding strategic behavior of China.

We find that it is crucial to account not only for export markets, but also for the domestic markets respecting their interactions and feedbacks if one analyses potential market power of strategic national players. If export market prices rise high enough, a national player will redirect domestic volumes to the export market as marginal revenues are higher. Therefore one may expect that the large Chinese supply compensates for any international coal demand shock or export capacities withheld, however, our analysis shows that this is not the case due to Chinese strategic trade policies applied.

These findings yield implications for policy makers in nations depending on coal imports: future supply and prices for internationally traded coal might possibly not be as cheap, stable and secure as believed by most market participants if emerging Asian nations increasingly pursue their national resource export strategies. This could make a reevaluation of the future role of coal in energy consumption of such countries necessary, as especially cheapness and abundance has been often cited as the main competitive advantage of coal compared to other energy sources.

On a more general level, our findings indicate that the increasing influence of non-western countries on world resource markets might change the current world trade paradigm. Strategic trade policy might become important also for markets which have been perceived as competitive before.

Possible future research could extend the analysis of strategic national players to account for the complete fuel complex or to internationally traded non-energy minerals. A multilateral market power analysis accounting for market power on the importer's side may also be an appropriate research venue.

Appendix

Proof of proposition in section 2.2: We consider a setup with a national player A which controls two firms which can produce a single commodity x: F_1 (exporter) and F_2 (domestic supplier). Further, there exists a domestic market D and an export market E where x can be sold to (price-taking) customers. Let $x_{1,D}$, $x_{1,E}$ and $x_1 = x_{1,D} + x_{1,E}$ be the supply of F_1 to the domestic market, the supply of F_1 to the export market and its total supply, respectively. The same holds for F_2. C_1 and C_2 are the respective convex cost functions of F_1 and F_2 with $c_1(x_1) = \frac{\partial C_1(x_1)}{\partial x_1} > 0\ \forall x_1$ and $c_2(x_2) = \frac{\partial C_2(x_2)}{\partial x_2} > 0\ \forall x_2$. The maximum production capacity of F_1 is limited to K. We assume that the exporter faces a cost disadvantage if supplying the domestic market and that the domestic supplier faces a cost disadvantage if supplying the export market. This cost disadvantage of both firms is represented by constant cost terms $t_{1,D} > 0\ \forall x_{1,D}$ and $\$ = t_{2,E} > 0\ \forall x_{2,E}$ for F_1 and F_2, respectively. The cost terms are defined such that $c_1(x_1) + t_{1,D} > c_2(x_2)\ \forall x_1, x_2 \in [0, K]$ and $c_2(x_2) + t_{2,E} > c_1(x_1)\ \forall x_1, x_2 \in [0, K]$ hold. Let further U and V be the volume supplied to the export and the domestic market, with $U = x_{1,E} + x_{2,E}$ and $V = x_{1,D} + x_{2,D}$. The inverse demand functions in both markets are decreasing in volumes.

We consider that A maximizes welfare in the domestic market D plus his producer rent from sales to the export market E less costs. His payoff function W_A is:

$$W_A = \int_0^V p_D(V)\mathrm{d}V + p_E(U)U - c_1(x_1) - c_2(x_2) - T(x_1, x_2.$$

In the following, we will compare a setup where A controls F_1 and F_2 and has access to export and domestic markets (*export&domestic setup*) with a setup that only accounts for the export market and A only controlling F_1 (*export-only setup*). We will show that $x_{2,E}$ can actually be greater zero rendering the *export-only setup* inconsistent.

Let μ be the capacity scarcity mark-up (dual variable) associated with the production constraint K for F_1. In case of a binding export capacity constraint K the equilibrium condition for firm A to supply the export market in the *export-only setup* is:

$$p_E(K) = -\frac{\partial p_E(U)}{\partial U}K + c_1(K) + \mu^{*'} \qquad \text{if } x^{*'}_{1,E} = K,\ x^{*'}_{2,E} = 0. \tag{18}$$

which simply means that marginal revenue equal marginal costs plus the scarcity rent. Equilibrium conditions for A in the *export&domestic setup* are:

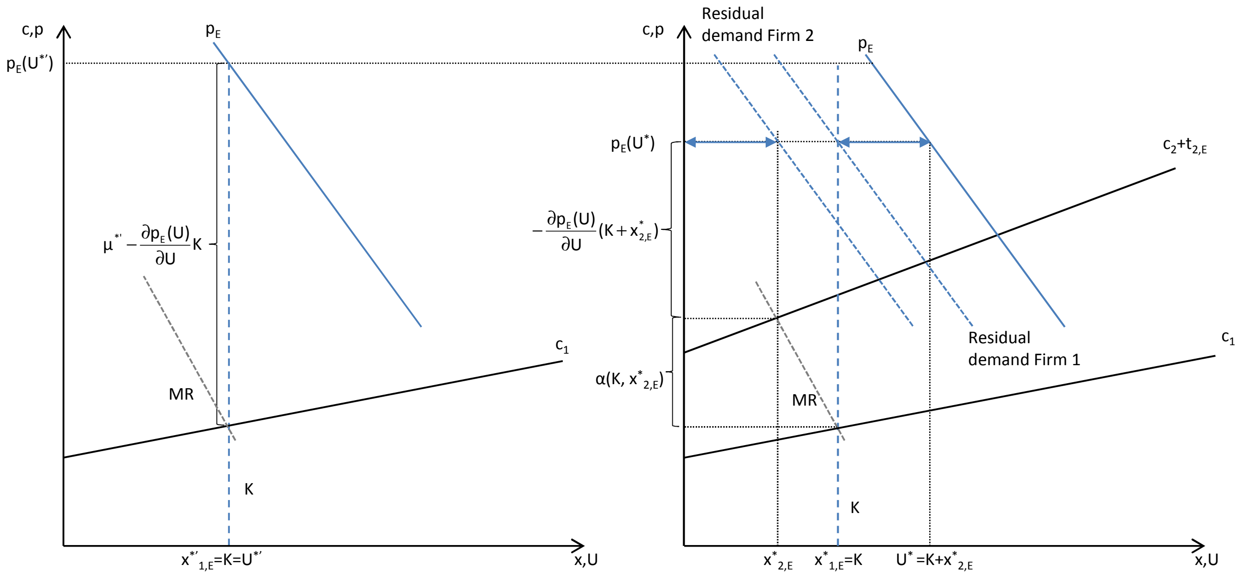

Figure 3: Export market equilibrium for the *export-only setup*(left) vs. *export&domestic setup* (right).

$$p_E(K + x^*_{2,E}) = -\frac{\partial p_E(U)}{\partial U}(K + x^*_{2,E}) + c_1(K) + \mu^* \quad \text{and} \tag{19}$$

$$p_E(K + x^*_{2,E}) = -\frac{\partial p_E(U)}{\partial U}(K + x^*_{2,E}) + c_2(x^*_2) + t_{2,E} \quad \text{if } x^*_{1,E} = K.\ x^*_{2,E} > 0. \tag{20}$$

From (19) and (20) we can see that

$$x_{2,E} = \begin{cases} > 0, & \text{if } \mu^* = c_2(x^*_2) + t_{2,E} - c_1(K) \\ = 0, & \text{if } \mu^* < c_2(x^*_2) + t_{2,E} - c_1(K) \end{cases} \tag{21}$$

in the *export&domestic setup*. □

Capacity scarcity is a function of the difference in export supply costs between both firms. In case of $x_{2,E} > 0$, F_2 covers the residual export market demand after F_1's maximum export market supply has been deducted (see Figure 3). F_2 will start supplying the export market as soon as its marginal export revenue equals marginal costs. In this case, the resulting price bias is:

$$p_E(U^{*'}) - p_E(U^*) = \mu^{*'} - \left(c_2(x^*_2) + t_{2,E} - c_1(K) - \frac{\partial p_E(U)}{\partial U} x^*_{2,E}\right), \tag{22}$$

which is always greater zero in the case of a decreasing demand function as total export market supply $U^* = K + x_{2,E}$ in the *export&domestic setup* is greater than export supply in the *export-only setup* $U^{*'} = K$.

The same inconsistency occurs if A acts in a competitive manner in the export market. However, the price bias is even higher: A would not account for the export price reduction inferred by delivering additional supply to the export market if it acts as a price taker. Thus, marginal revenue from supplying the export market equals export price leading to a even higher redirection of domestic supply. In this case, domestic supply to the export market acts as a backstop for export market prices in the case we also consider the domestic market. The price bias in a competitive setup would therefore be:

$$p_E(U^{*'}) - p_E(U^*) = \mu^{*'} - (c_2(x_2^*) + t_{2,E} - c_1(K))\,. \tag{23}$$

Table 3: Model sets and indices

$n \in N$	Model region nodes
$m \in M \subset N$	Mining region nodes
$e \in E \subset N$	Export terminal nodes
$d \in D \subset N$	Demand region nodes
$(i,j) \in A \subset N \times N$	Transport arcs
$p \in P$	Model players
$m \in M_p \subset M$	Mine regions controlled by player p
$e \in E_p \subset E$	Export terminals controlled by player p

Table 4: Model parameters

C_m^p	Production cost function of player p in mine region m
Cap_m^M	Mining capacity in mining region m
Cap_e^E	Throughput capacity at export terminal e
$Cap_{(n,n')}^T$	Transport capacity between node n and node n'
$c_{(n,n')}^T$	Transport costs between node n and node n'
c_e^E	Turnover costs at export terminal e
a_d	Intercept of inverse demand function in demand region d
b_d	Slope of inverse demand function in demand region d
$t^{p \to d}$	VAT adjustments for exports from player p to demand region d
$r^{p \to d}$	Player p's aggregate conjecture for demand region d of how exports of all other competitors change given a change in its own export volume

Table 5: Model variables

s_m^p	Production of player p in mining region m
$q_{(n,n')}^p$	Transport volume of player p from node n to node n'
v_d	Import price for player p in region d
x_d^p	Trade volume from player p from mining region m to demand region d
λ_n^p	Dual variable associated with the energy balance constraint representing marginal costs of supply of player p to node n
μ_m^p	Dual variable associated with the mine capacity constraint representing mine capacity scarcity rent of player p in mining region m
ϵ_e^p	Dual variable associated with the export terminal capacity constraint representing export capacity scarcity rent of player p in export terminal e
$\phi_{(n,n')}$	Dual variable associated with the transport capacity constraint representing transport capacity scarcity rent on arc $a_{n,n'}$

Table 6: Actual and modeled steam coal trade market flows in million tonnes in 2008

	Japan	Korea (S.)	Taiwan	U.S.	China	Europe	India	Other
Actual trade volumes in Mt								
Indonesia	24.4	23.2	23.7	2.1	22.2	19.1	19.0	23.8
Colombia				27.8		35.9		9.5
Australia	74.1	20.5	20.6	0.1	1.7	2.8	0.8	6.2
South Africa	0.1	1.0		0.8		48.2	7.9	3.7
Russia	8.9	6.4	0.9		0.5	68.4		0.6
U.S.	0.3	0.3			0.2	13.5	0.1	4.0
China	11.8	16.7	11.2	0.1		1.7	0.8	1.6
Other	2.0	0.9		2.5	16.8	11.0		7.5
Trade shares for China - Indonesia duopoly without export quota								
Indonesia	16.1	15.9	19.9		38.7	21.5	25.0	23.2
Colombia				25.9		40.0		
Australia	79.3	27.5	23.7					
South Africa			6.4			42.0	14.1	
Russia		23.4				69.3		
U.S.	21.6					10.4		6.5
China	12.6	8.9	6.4			7.3	5.2	2.9
Other			4.1		15.1	15.3		
Trade shares for Indonesia monopoly with export quota								
Indonesia	15.3	15.9	19.9		55.4	19.8	22.9	22.6
Colombia				25.9		40.0		
Australia	93.9		36.6					
South Africa						39.0	22.2	1.3
Russia	12.0	11.4				69.3		
U.S.	8.7					22.9		6.9
China		48.6						
Other			4.1		15.1	14.9		
Trade shares for perfect competition with export quota								
Indonesia	36.7	32.2	64.7		29.3			26.0
Colombia				25.9		40.0		
Australia	77.0					53.5		
South Africa						8.1	54.4	
Russia	23.4					69.3		
U.S.						28.7		9.8
China		48.6						
Other					19.2	12.1		
Trade shares for perfect competition without export quota								
Indonesia	0.5	15.9	65.4		79.9			27.2
Colombia				34.3		31.5		
Australia	58.7					71.8		
South Africa						2.7	59.9	
Russia	23.4					69.3		
U.S.						27.3		11.2
China	55.9	66.1						
Other					19.2	12.1		

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