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Have Prices of Internationally Traded Steam Coal been Marginal Cost Based?♦

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Abstract

During 2007 and 2008 steam coal prices soared to unprecedented levels. Since then much has been speculated about the drivers of these price peaks. This paper is concerned with the costs of steam coal allocation in the seaborne market and their influence on the price equilibrium. It presents an optimisation model that differentiates between mining technologies and therefore allows to analyse the effects of input price escalation on marginal costs in detail. Since 2005 input prices of commodities used in coal mining and bulk carrier freight rates increased significantly, causing marginal costs to rise. However, this affected suppliers along the global supply curve differently. We find that low-cost intramarginal suppliers experienced higher cost increases than marginal suppliers due to the different production technologies applied. Based on our results we conclude that prices of internationally traded steam coal are generally marginal cost based. However, the all time price spike of 2008 was not caused by cost escalation. We suppose that short-run capacity scarcity was responsible for the soaring prices in this year. Hence, marginal costs are a major determinant of the price equilibrium in the seaborne steam coal market given that capacity is not scarce.

Keywords: Steam coal, marginal costs, mining technologies, cost escalation, price peak

JEL classification: C61, L11, L71, Q31

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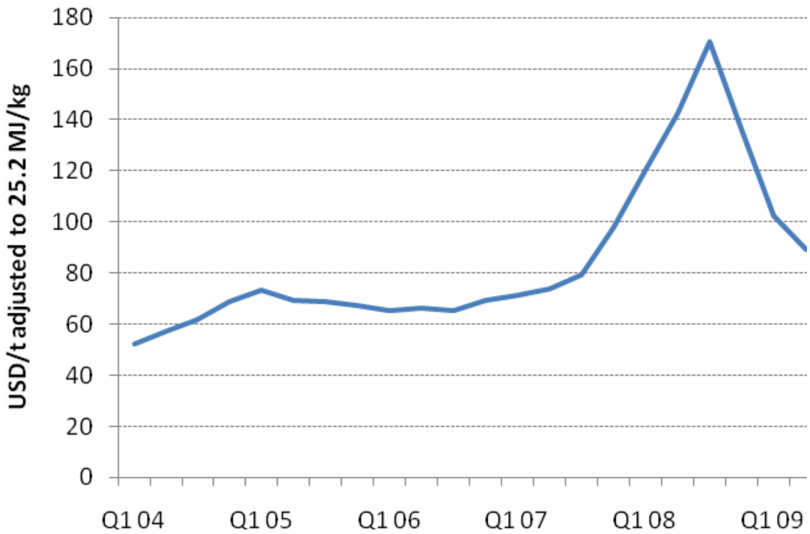
1. Introduction

Coal is after oil and before natural gas the second most important primary energy source. It is mainly used for electricity and heat generation. About 36% of the global electricity generation is based on hard coal. During the last decade international steam[1] coal trade increased dynamically. Steam coal prices used to be relatively low and not very volatile for many years[2]. However, during the years 2007 and 2008 prices suddenly soared and reached an unprecedented peak of 210 USD/t in mid-2008. Finally, prices collapsed in the second half of 2008 dwindling down to 61 USD/t in spring 2009 (see figure 1).

Figure 1: Average quarter yearly German steam coal border prices 2004-2009



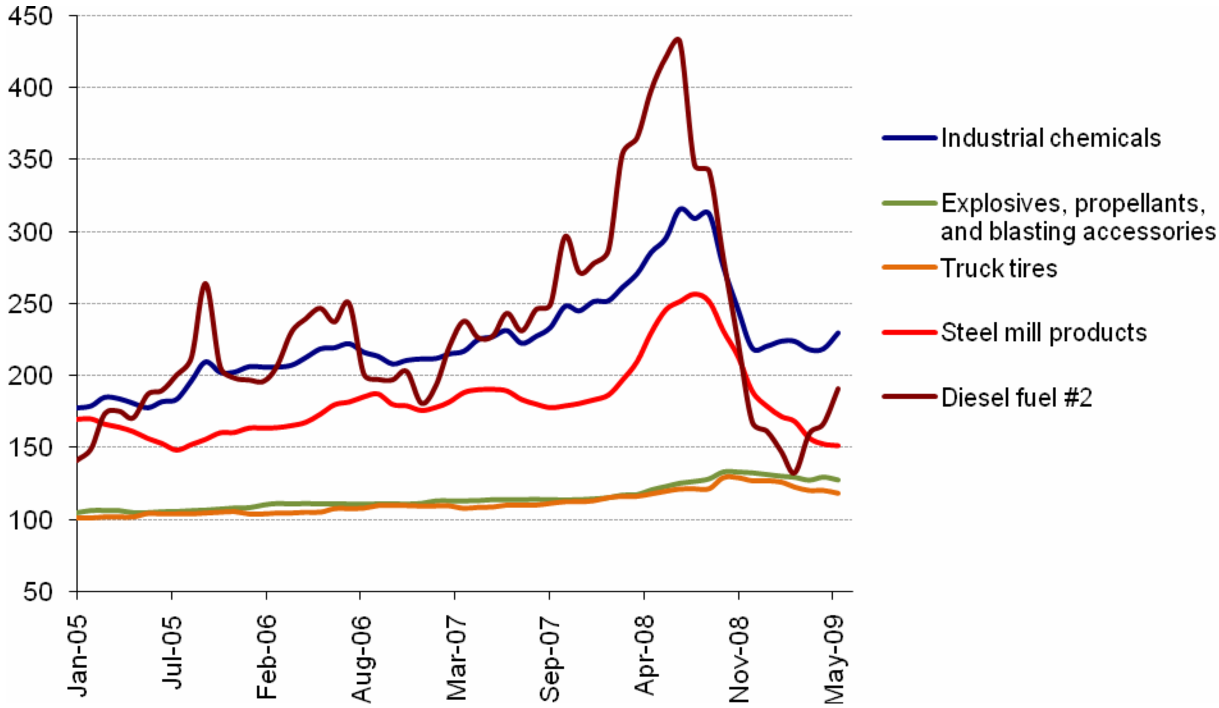
Source: BAFA (2010)

However, during the same period not only coal prices peaked. Bulk carrier freight rates soared to all time heights. Moreover, a world-wide economic boom caused prices of many commodities crucial to coal mining also to increase (see figure 2). Diesel fuel, steel, explosives and tyres are important inputs in coal production. These commodities are traded on world markets. Price fluctuations therefore affect mining companies worldwide. Other important factors such as labour costs, electricity prices or exchange rates are subject to national economic developments. However, a country-specific analysis shows that in many cases these factors also contributed to the mining cost increases. This paper takes a historical perspective and focuses on the costs of coal allocation. Hence, we analyse the influence of

[1] Steam coal is mainly used in electrictiy generation whereas coking coal is used for metallurgical purposes.
[2] A comparison of German border prices (published by BAFA 2010) of oil, gas and hard coal showed that coal price volatility was relatively low and coal prices are significantly lower than the other fuels'.

marginal costs on coal prices during 2005 to 2009. A computer-based optimisation model focussing on the supply chain of the seaborne steam coal market is presented. It simulates cost minimal trade flows and estimates marginal costs on the seaborne steam coal world market. Comparing these marginal cost levels with real market price data allows us to determine the extend to which the price spikes during 2007 and 2008 were cost driven. Due to the rising significance of steam coal in global electricity generation a thorough understanding of costs and pricing in international trade is crucial for energy policy makers world-wide.

Figure 2: Price indexes of commodities used in coal mining 2005-2009



Source: BLS (2009)

The remainder of the paper is structured as follows: Firstly the literature on both, coal market modelling and spatial equilibrium modelling is reviewed in brief. Secondly, a detailed description of the model and its properties is given. Beside the formulation of the mathematical problem, the underlying economic propositions are discussed regarding the structure and characteristics of the real market. Thirdly, the supply chain data input is described in detail. Finally, model results are discussed and conclusions are drawn.

2. Related Literature

The steam coal world markets' most obvious characteristic is its geographical structure. Steam coal demand regions are not necessarily at the location of the coal fields. Coal fields are dispersed widely over the globe and internationally traded coal is usually hauled over long distances to the demand centres. This spatial structure causes certain implications for the market equilibrium. The economics of such spatial markets have been scrutinised by researchers in depth. In an early approach Samuelson (1952) combines new insights from operations research with the theory of spatial markets and develops a model based on linear programming to describe the equilibrium. Using marginal inequalities as first order conditions, Samuelson models a net social welfare maximisation problem under the assumption of perfect competition. Based on Samuelson's findings Takyama and Judge (1964) develop an approach that uses quadratic programming. Moreover they present algorithms that are able to efficiently solve such problems also in the multiple commodity case. Harker (1985) is particularly concerned with imperfect competition on spatial markets. He extends the monopoly formulation as presented in Takayama and Judge (1971) to a Cournot-Nash formulation and suggests algorithms to solve the generalised problems.

So far not many applications of these methods to the steam coal world market exist in the literature. Coal market modules are part of global energy models as they are used by the International Energy Agency (IEA) and the Energy Information Administration (EIA). The coal market module of the IEA's World Energy Model is a cost minimisation approach based on a constrained linear programme, and therefore assuming competitive markets implicitly. A similar approach is applied in the International Component of the Coal Distribution Submodule (CDS-IC) as it was developed by the EIA. The CDS-IC simulates international steam coal trade under the competitive conditions and is part of the Coal Market Module.

However, it has also been doubted in the literature that the international steam coal market is organised competitively. Kolstad and Abbey (1983) and Kolstad (1984) analyse strategic behaviour in international steam coal trade in the early 1980s using a mixed complementary model (MCP). Besides perfect competition they model different imperfect market structures. Firstly, they model South Africa as a monopolist, secondly they examine a duopoly consisting of South Africa and Australia, thirdly, they test for a duopoly with a competitive fringe and Japan as a monopsonist on the demand side. The authors find that the duopoly/monopsony situation simulates the actual trade patterns well. Labys and Yang (1980) develop a quadratic model for the Appalachian steam coal market under the conditions of perfect competition including elastic consumer demand. They investigate several scenarios with different taxation, transport costs and demand parameters and analyse the effect on steam coal production volumes and trade flows. Yang et al. (2002) develop conditions for the Takayama-Judge spatial equilibrium model to collapse into the classic Cournot model. They demonstrate that in the case of heterogeneous demand and cost functions, the spatial Cournot competition model is represented by a linear complementary programme (LCP). They find out that the US coal market cannot satisfactorily be described by the spatial Cournot competition. In a recent study Haftendorn and Holz (2008) analyse the steam coal market with a complementary model. The objective function includes a market power parameter allowing to examine competitive and strategic Cournot behaviour. Major exporting countries are assumed to have linear supply functions and to be able to withhold quantities strategically. Their results suggest that the steam coal world market is not subject to Cournot competition and that the results in the scenario assuming perfect competition represent real market data better.

3. Model Description

Compared to the markets for oil and natural gas, we consider the seaborne steam coal market competitively organised and well integrated.[3] In the seaborne steam coal market a large number of both, state-run mining enterprises and privately owned companies compete with each other. The largest four internationally operating mining companies together controlled only about 28% of the seaborne mining capacity in 2007.[4] Given the availability of additional mining capacity from the domestic markets, the potential to exercise market power on the seaborne steam coal market seems currently quite low. Theoretically, the spatial price equilibrium in such a market is fundamentally marginal cost based (see e. g. Samuelson (1952)).

The optimisation model is based on the classic transport problem.[5] The time horizon of the model $T = \{2005, 2006, ..., t, ...2009\}$ includes periods on an annual basis. It consists of a network *NW(N,A)*, where *N* is a set of nodes and *A* is set of arcs between the nodes. The set of nodes *N* can be divided into two subsets $N \equiv E \cup I$, where $i \in E$ is an export region and $j \in I$ is a demand node. The two different roles of nodes are mutually exclusive $E \cap I \equiv \varnothing$. The set of arcs $A \equiv E \times I$ consists of arcs $a_{(i,j)}$ where *(i,j)* is a tuple of nodes $i, j \in N$.

Mining costs, average inland transport costs and port terminal costs add up to a quadratic FOB (free-on-board) supply function depending on the produced quantity $q_{i,t}$ per export node $S_{i,t}(q_{i,t})$. Seaborne transport costs $tc_{i,j,t}$ per unit $qt_{i,j,t}$ shipped. However, the transport cost parameter $tc_{i,j,t}(d_{ij})$ depends on the distance d_{ij} between *i* and *j*. The transport cost function

[3] Empirical evidence for steam coal market integration is e.g. given in Li (2008) or Zaklan et al (2009). Haftendorn/Holz (2008) find no empirical evidence for market power in international steam coal trade.

[4] See Rademacher (2008) p.73, considered are BHP Billiton, Anglo Coal, Xstrata/Glencore and Rio Tinto.

[5] See e.g. Dantzig et al (1954)

$tc_{i,j,t}(d_{ij})$. A regression analysis of bulk carrier freight rate data has shown that generally $tc' > 0$ and $tc'' < 0$. Hence, freight rates increase with the distance travelled but the increment is less than linear. Individual transport cost functions were calculated for every year based on historical data[6]. Demanded volumes $D_{j,t}$ are modelled exogenously and therefore inelastic to price variations.

The optimisation model is formulated as a cost minimisation problem with a non-linear convex objective function and several linear constraints. The optimal solution of this programme is dual to the optimal solution of a welfare maximising problem. Thus, our approach implicitly assumes perfect competition. Production costs in node $i \in E$ correspond to the integral under the FOB (free-on-board) supply function:

$$c_{i,t} = \int_0^{q_{i,t}} S_{i,t}(q)\,dq$$

Adding seaborne transport costs and summing over all production nodes yields the system costs per year:

$$SC_t = \sum_i c_{i,t} + \sum_i \sum_j qt_{i,j,t} * tc_{i,j,t}$$

The objective function minimises the intertemporal total system costs. The optimal solution of this problem is constrained by the following restrictions. The market equilibrium restriction guarantees that demand in all regions $j \in I$ is fully satisfied:

$$D_{j,t} \le \sum_i qt_{i,j,t}$$

The following restriction ensures that coal production in region $i \in E$ is at least as high as the exports from $i \in E$ to all demand regions $j \in I$ exports:

$$q_{i,t} \ge \sum_j qt_{i,j,t}$$

Furthermore exports are constrained by the available mining or infrastructure capacity $Q_{i,t}$. The optimisation model is implemented in GAMS and solved using IPOPT[7].

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[6] Bulk carrier freight data were provided by McCloskey Coal Information, Frachtkontor Junge & Co, Baltic Exchange and various sources from the internet.
[7] See Wächter/Biegler (2006).

Table 1: Model regions

Export regions	Demand regions
New South Wales/open cast	North West Europe (ARA)
New South Wales/underground	Southern Europe and Mediterranean
Queensland/open cast	Japan
Queensland/underground	South Korea
South Africa/open cast	Taiwan
South Africa/underground	China
Indonesia	India
Russia (Pacific)	Chile
Russland (Baltic Sea)	USA (Gulf of Mexico)
Colombia	South East Asia
China (Shanxi)	Brasil
Central Appalachia	
Venezuela	
Vietnam	

4. Dataset

The database used in this analysis stems from several extensive research projects conducted at the Institute of Energy Economics at the University of Cologne. Steam coal market data has been acquired from a multitude of different and potentially heterogeneous sources. Although steam coal market data seems scarce at a first glance, various institutions, researchers, experts and companies have published useful information. General steam coal market data is for example published by institutions like IEA and EIA.[8] Detailed data on supply chain costs, steam coal demand and production of major players are available from the IEA Clean Coal Centre.[9] Further publications include analyses from employees working for international utilities and coal industry newsletters.[10] National statistics bureaus and ministries concerned with minerals, energy and resources provide detailed information. Notable examples are ABARE, US Geological Survey, Bundesanstalt für Geowissenschaften und Rohstoffe, Australian Bureau of Statistics, DANE, BLS and Statistics South Africa. During the research projects at the Institute of Energy Economics at the University of Cologne company annual reports and presentations related to the steam coal market have been evaluated and expert

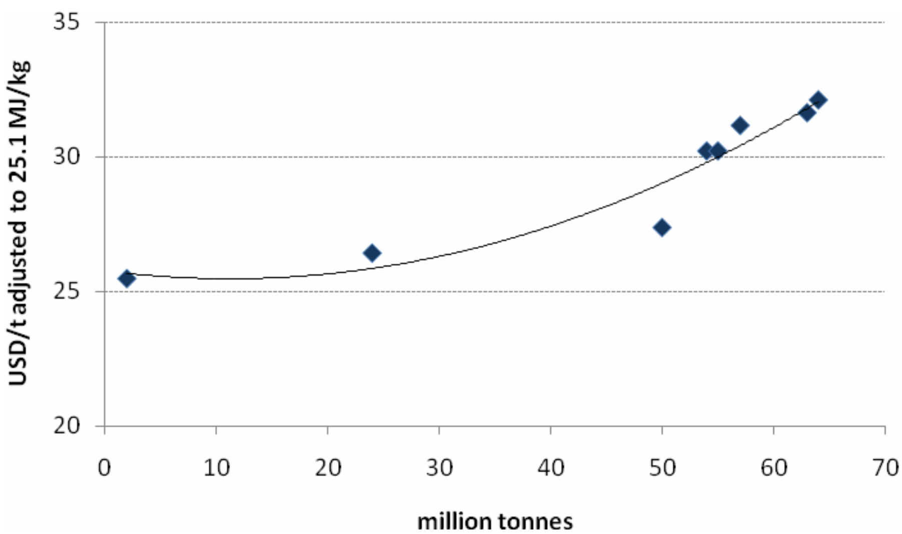
[8] See IEA Coal Information (2009) and IEA (2010) World Energy Outlook, EIA (2009) Annual Energy Outlook and EIA (2010) International Energy Outlook.
[9] See Baruya (2007, 2009), Minchener (2004, 2007) and Crocker/Kowalchuk (2008).
[10] See e.g. Kopal (2007), Rademacher (2008), Bayer et al. (2009) and Ritschel/Schiffer (2005, 2007). The McCloskey Coal Report is regularly reviewed.

interviews conducted. Moreover, our database is regularly discussed and reviewed with industry experts.

4.1 Mining costs

Costs for mining consist of overburden removal and extraction costs, processing and washing costs as well as transportation costs within the colliery. Our data on mining costs is based on expert interviews and the evaluation of annual reports and literature sources as described above. Since this data stems from heterogeneous sources and is mostly based on cost ranges and mining costs of representative mines we regard our data only as a proxy for real mining costs. The lack of data on some mines might cause distortions if we would model every single mine explicitly. Therefore we fit the available data of mine mouth cash costs and mining capacity to a polynomic marginal cost function by ordinary least squares. This method yields a supply curve that comprises the main characteristics and cost levels of each mining region. Figure 3 depicts Colombian mining costs and the approximated marginal cost function as an example for 2005. As coal qualities vary between the mining regions, calorific values are generally adjusted to 25.1 MJ/kg using data from Ritschel (2010), BGR (2009) and IEA (2009).

Figure 3: Example of mining costs for Colombia and approximation of marginal cost function for 2005



Source: Baruya (2007), Ritschel/Schiffer (2007) own database

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

Table 2: Input factors and relative importance in coal mining in 2005

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

Source: ABS (2006), Meister (2008), own database

The mining cost curves are escalated according to the cost structures using price index data for the above mentioned commodities from various statistical offices (see e.g. figure 2). Furthermore, productivity figures and country specific exposures to fluctuations of exchange rates are included. This method yields the shifts in supply curves for the period 2006-2009.

4.2 Transport costs, port handling fees and seaborne freight rates

Inland transport costs depend on the transportation mode and the distance from the mine fields to the export terminal. Coal is mainly hauled by rail or truck and in some cases by river barge. Inland transport costs vary between the mining regions. While they are below 4 USD/t for the bulk of the Colombian production they may be as high as 25 USD/t for the transport from the Russian Kuzbass basin to the Baltic ports. We estimated the relative impact of diesel and electricity cost escalation by the relative importance of truck and railway haulage for main transport routes. Port handling fees comprise costs for unloading, storage and loading onto vessels. Depending on the country, royalties and taxes, have to be paid. Country specific average inland transport cost and port handling fees are added to the mining cost curve to derive FOB supply functions. Seaborne bulk carrier freight rates are a major cost component of internationally traded steam coal. Freight rates were not escalated since real market freight data was used in the analysis for all years.

4.3 Demand data

The data on seaborne steam coal demand was derived from IEA Coal Information and the German Coal Importers Association.[11] Table 3 presents the demand data used.

Table 3: Steam coal demand in million tonnes 2005-2009

	2005	2006	2007	2008	2009
North West Europe	99	109	106	115	115
Mediterranean	68	74	78	61	64
North America	32	41	41	36	25
Latin America	9	10	11	15	11
China	30	46	52	45	89
Taiwan	59	57	57	59	58
Japan	111	113	110	121	114
Korea	56	62	69	71	82
India	21	27	34	31	41
South East Asia	21	27	36	37	42

Source: IEA Coal Information; German coal importers' association

5. Results

Generally, coal supply costs increased world-wide during 2006 and 2009 due to input price escalation. Table 4 presents an overview of the cost increases for the model mining regions. Clearly, mining cost escalation affected producers differently. Major exporters with a large share of open cast production like Indonesia, Colombia or Venezuela generally experienced higher cost increases. Producers with a high proportion of underground mines like the US, China, South Africa or Australia were less affected. This is due to the different cost structures of underground mining operations. Underground mining technologies rely to a larger proportion on labour costs and electricity prices and other locally sourced materials. Except for steel products which are also an important input in deep mining, the high prices of fuel and oil derivatives, explosives and tyres did not raise underground mining costs.

[11] See IEA Coal Information (2007, 2008, 2009) and Ritschel (2010).

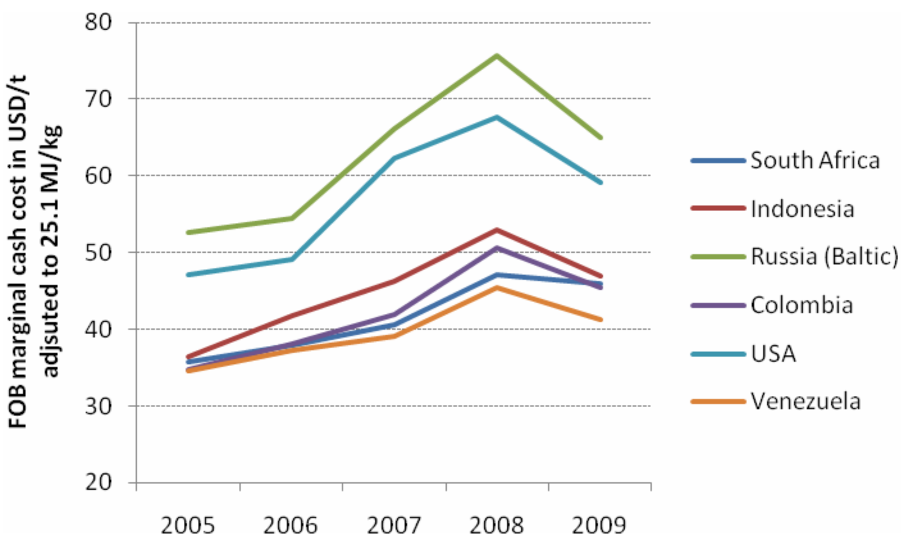
Table 4: Mining cost increases for major exporters 2006-2009

in %	2005-2006	2006-2007	2007-2008	2008-2009
USA (Appalachia)	8	4	15	-3
Russia	17	14	24	-8
Colombia	5	11	25	-15
Indonesia	22	11	19	-11
South Africa UG	6	10	19	-10
South Africa OC	8	12	21	-8
China	8	14	17	-3
Venezuela	10	6	21	-9
Vietnam	6	13	18	-5
New South Wales OC	10	8	12	-2
New South Wales UG	5	11	7	-1
Queensland OC	6	11	11	-3
Queensland UG	-1	12	4	-1

Source: own calculations

Figure 4 shows model marginal FOB costs for Europe's main suppliers. Exporting countries like Colombia, South Africa or Venezuela are low-cost suppliers for the Atlantic Market. Prices usually exceed their marginal costs. Russia and the USA are the marginal suppliers in the Atlantic market and set the price.

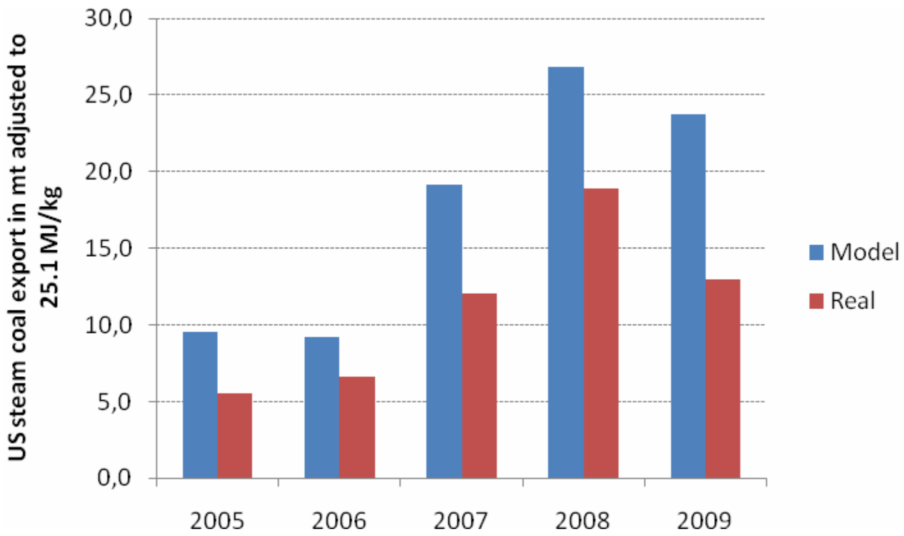
Figure 4: FOB marginal cash costs for major suppliers in the Atlantic market 2005-2009



Source: own calcualations

There are two reasons for the marginal cost increase. Firstly, supply chain costs rose due to higher input prices. Secondly, steam coal export mining capacity development did not keep up with demand growth. Increasing capacity utilisation enabled high-cost mines that are normally extramarginal, to sell to the seaborne steam coal market profitably. This mining capacity usually serves their respective national markets but generally has the infrastructure and the necessary coal quality to export its product. Such mines exist in most coal exporting countries to a certain degree. However, most of these mines are found in the Appalachians. With mining costs up to 50 USD/t and inland transport costs up to 25 USD/t these mines need a relatively high price level on the international market to fully recover their costs. Therefore the USA act as a "swing-supplier" on the seaborne steam coal market. In times of low prices, steam coal is imported and only small quantities are exported. During tight market situations with high prices significant volumes are exported. This effect was clearly observable in the real market. Figure 5 depicts US steam coal exports as a model result and real market export data. Both, model results and real market data support the United States' role as a swing supplier. Although, model exports are systematically higher than real market exports the model simulates the trend well. The inaccuracy most likely stems from the negligence of the US national coal market in the model.

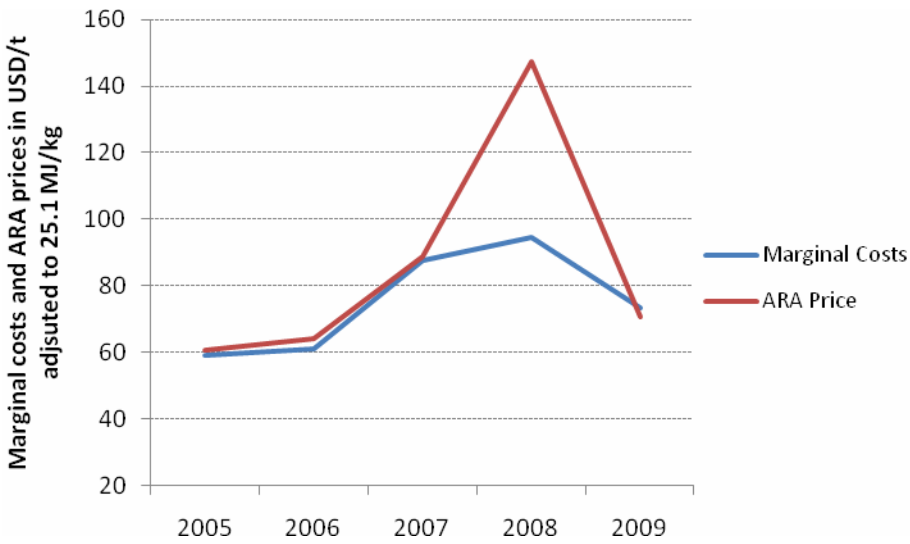
Figure 5: US steam coal exports in million tonnes 2005-2009



Source: own calcualations

However, looking at FOB marginal costs only, gives a distorted view on delivered marginal costs as they lack freight rates which are a major cost component. Figure 6 compares steam coal marker prices for the ARA (Amsterdam/Rotterdam/Antwerp) port region and model CIF (cost-insurance-freight) marginal costs for the North West Europe region for the years 2005 to 2009. Obviously, steam coal prices were fundamentally marginal cost based in the years 2005 to 2007 and 2009. Marginal cost increases due to mining cost escalation and high freight rates are able to explain the fairly high average price level of 89 USD/t in 2007. However, in 2008 there is a large gap between marginal costs and prices. Although costs increased, prices exceeded the marginal cost level by more than 50%. With the uprising of the global financial crisis and the economic downturn in late 2008 both, marginal costs and steam coal prices dropped. During 2009, the model results suggest that prices were marginal cost based again.

Figure 6: Comparison of CIF marginal costs with steam coal marker prices (North West Europe)



Source: Marginal costs - own calcualations; price data - VDKI (2010).

6. Conclusions

Our findings suggest that marginal costs are a major determinant of prices in the seaborne steam coal market. Escalating input prices and freight rates have increased coal supply costs across the board. However, the magnitude of the effect depends on the mining technology applied. Open cast operations generally experienced higher cost increases than underground collieries. Since marginal mines in the Atlantic market are usually underground operations, marginal costs have increased little in comparison to the industry average. Hence, cost escalation caused an upward shift and a flattening of the global supply cost curve. From our results we conclude that cost escalation contributed significantly to the peaking prices in 2007 and 2008. Yet, despite the cost escalation, a large gap between costs and prices remains unexplained during 2008. This may be due to a number of reasons: Firstly, inelastic steam coal demand is a reasonable approximation when the focus is on costs. However, prices and marginal costs diverge even in markets with perfect competition when demand exceeds the available capacity. Consequently, increasing prices then ration demand to a level that can be supplied with the available capacity. According to our analysis steam coal supply chain capacity utilisation was about 97% in 2008. In reality, capacity may have been scarce during the first half of 2008 due to high demand and short term supply bottlenecks. Given, the high natural gas and oil prices during 2008, steam coal price elasticity in power generation may have been small causing prices to rise at very high levels. Secondly, interactions between the thermal and the coking coal market have not been accounted for. A small proportion of high quality steam coal may also be used as low quality metallurgical coal. The boom on global steel markets may have forced some steel mills to burn coals which would otherwise have served as thermal coal and thus shortening steam coal supply additionally. Thirdly, the vast national markets of China and the USA may have had an impact on steam coal prices in 2008. Both Chinese and American exports remained under their potential, leading to the conclusion that national demand may have restricted exports. Finally, the abuse of market power in the tight market situation of 2008 cannot be rejected. Although our findings for 2005-2007 and 2009 suggest that the steam coal market works in a competitive way, strategic shortening of supply by some companies might still be possible when capacity is scarce. Given that all capacity was utilised withholdings of small volumes may have caused significant price increases.

In summary, the analysis presented in this paper is focused on the supply side of the steam coal world market and allows estimation of marginal coal supply costs. These marginal supply costs approximate real market prices well for years without capacity scarcity. However, further research particularly concerning the demand side of the market is needed to refine the model in terms of price predictions.

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