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Berlin, December 2009

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IMPRESSUM

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

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The Globalization of Steam Coal Markets and the Role of Logistics: An Empirical Analysis

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DIW Berlin (German Institute for Economic Research)

December 2009

Abstract

In this paper, we provide a comprehensive multivariate cointegration analysis of three parts of the steam coal value chain – export, transport and import prices. The analysis is based on a rich dataset of international coal prices; in particular, we combine data on steam coal prices with freight rates, covering the period December 2001 until August 2009 at weekly frequency. We then test whether the demand and supply side components of steam coal trade are consistently integrated with one another. In addition, export and import prices as well as freight rates for individual trading routes, across regions and globally are combined. We find evidence of significant yet incomplete integration. We also find heterogeneous short-term dynamics of individual markets. Furthermore, we examine whether logistics enter coal price dynamics through transportation costs, which are mainly determined by oil prices. Our results suggest that this is generally not the case.

JEL Codes: L11, Q41, C22

Keywords: steam coal, market integration, multivariate cointegration

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We thank Frank Wolak, Richard K. Morse, and Burcu Erdogan for insights and fruitful discussion; earlier versions of the paper were presented at the 32nd International Conference of the IAEE (September 2009, Vienna) and the 3rd Conference on energy research ('Enerday', April 2009. Dresden). This paper is part of the "Global Coal Market" research Program at PESD Stanford. All remaining errors are ours, the usual disclaimer applies.

1 Introduction

The price formation for steam coal, the most important type of coal and its dynamics is often unclear even to many insiders, and widely unknown even to the specialized economics community. Although coal is one of the most important commodities traded internationally, the market remains largely non-transparent, and is far less sophisticated than the markets for oil and natural gas. The international markets have remained segmented for a long time, in particular between the Atlantic and Pacific basins, but also with respect to coal qualities, shipping vessel size, and sectoral demand.

To our knowledge there has been no systematic analysis of global coal price dynamics. Most of the common knowledge about how coal markets function appears to be based upon anecdotal evidence promulgated by market participants. Even the most "standardized" prices, such as the API-2 (CIF[2] price received in the ARA-region Amsterdam-Rotterdam-Antwerp) and the API-4 (FOB South African coal price out of Richards Bay), derive from individual statements by selected traders willing to reveal the prices of their latest deals. We note in passing that an environment in which information brokers pay for information is ripe for market manipulation. Also, a high market concentration on the supplier side (China, the US, South Africa, Indonesia and Australia together comprise 78% of world steam coal production) adds to the potential to drive prices away from competitive levels.[3]

This potential may have diminished due to increased competition around the turn of the century with the advent of new shipping sizes, fewer constraints on downloading and uploading port facilities, and the emergence of liquid "hubs" in several market segments, such as South Africa and Australia. Furthermore, the price spike during the recent "oil price crisis", where coal prices have peaked similarly drastically as oil prices, may have caused greater awareness by potential new market participants about the available rents in this business. Increasing price pressure on the major buyers of steam coal, i.e. electric utilities, is an additional factor driving towards price integration. The fact that even Australia has entered the Atlantic market is also considered as an indication that the globalization of coal markets has advanced.[4]

On the other hand, a closer look at the technical aspects of the markets and the anecdotal evidence about the lack of reliable marker prices for globally traded steam coal suggest a less sanguine interpretation of coal market activity. The use of steam coal in boilers for electricity generation critically hinges upon the tight specification of coal composition, e.g., heat value, ash, sulphur, moisture content, granularity, etc. Steam coal is not easily standardized, which greatly reduces the applicability of commodity price indices, such as the API-2 and the API-4. Today, there is no world-wide price index for this important commodity that is based on publicly quoted supply and demand.

[2] CIF is the price including cost, insurance and freight; FOB is free on board, i.e. the price paid at the export location.

[3] Even though there are many smaller producers involved in steam coal mining and international trade, four large companies dominate the international market, i.e. export capacities: BHP Billiton, Rio Tinto, XStrata, and Anglo. The four were responsible for almost one-third of global steam coal export capacity in 2007 (Rademacher, 2008).

[4] "The inability of producers in the Atlantic to completely meet the coal trade demand in that region has allowed Australia to be the price setter in the Atlantic market as well." (EPRI, 2007, 1-6).

Even the most commercialized route, South Africa to ARA, has been unable to produce a market price that can serve as a basis for liquid spot and forward trading.

Furthermore, an analysis of the international steam coal trade would be incomplete without taking into account that logistics are of paramount importance for the industry. International steam coal prices depend very strongly on logistics costs, such as railway or domestic shipping (inland), transhipment, sea transport (international trade) and transportation to the final customer (inland). In turn, logistics costs depend on both fuel oil prices and the availability of transport capacities, since steam coal competes for capacity with other dry bulk products, such as coking coal. Thus, a comprehensive market analysis must incorporate both extraction costs and the price and availability of the logistical services needed to bring steam coal to the end-users.

Specific segments of international coal markets have been analyzed in the academic literature, albeit with heterogeneous results. There is no clear consensus whether the "globalization" of steam coal trading has already occurred. Ellermann (1995) documents that the U.S. was the price setter in a unified world coal market from the 1970s until the 1990s. The two papers by Ekawan and Duchêne (2006) and Ekawan et al (2006) suggest that the international markets for steam coal were already integrated in the early 2000s;[5] however, the papers do not provide econometric evidence to support this hypothesis. Warell's (2005) empirical work on quarterly import prices suggests regional markets but without a clear trend towards integration. In an extension, Warell (2006) argues that the integration of markets in Europe and Japan was interrupted during the 1990s. Li (2007) shows that monthly export prices from the main steam coal exporting regions are generally highly integrated, with the exception of Indonesia. EPRI's (2007) analysis also tends to indicate global price transmission via freight rates (and exchange rates), showing that "the role of Australian coal price is similarly important now to the Atlantic market" (EPRI, 2007, 1-8). This research suggests that due to a change in relative prices the U.S. lost its position as a swing supplier in the Atlantic basin, and was replaced by Colombian (and Venezuelan) producers with lower delivery costs to the U.S. East Coast, and thus to Europe as well.

In this paper we provide a comprehensive analysis of the global price dynamics of steam coal. We compile a richer data set than was used in the literature so far in terms of scope and frequency, and conduct a comprehensive multivariate cointegration analysis of three major pieces of the value chain of steam coal, namely export, transport and import prices, both separately and jointly. We perform our analysis at the level of individual routes, at the regional (i.e. basin) level, and at the global (i.e. inter-basin) level. We propose that although the industry is gradually moving from a segmented, OTC-dominated activity to a higher degree of commoditization and international integration, a truly integrated single-world coal market has yet to be achieved.

Our data is sampled at weekly frequency, whereas existing literature on international coal market integration is based on monthly or even quarterly data. In addition to coal prices our data set includes

[5] "With regard to regional markets, coal from any of the major exporters will find markets in either Europe or Asia, depending principally on freight costs." (Ekawan and Duchêne, 2006, 1487).

freight rates which have not previously been used in an analysis of coal market integration. We test whether the demand side of the steam coal market, proxied by the CIF price, and the supply side, i.e. export prices plus freight rates, are integrated among each other, and whether systems of demand and supply are integrated when exports, imports, and freight rates are combined for individual trading routes, across basins, and globally. We find evidence of significant yet incomplete integration. Using the weekly frequency of our data we also estimate short-term dynamics of individual markets. Furthermore, we examine whether logistics enter the steam coal market via the direct transmission of the oil price, the main driver of seaborne transport costs, in coal prices and freight rates. Finding that the oil price is not linked to export, import, or transport prices in any systematic way, we conclude that logistics enter the system of steam coal prices in a more complex manner.

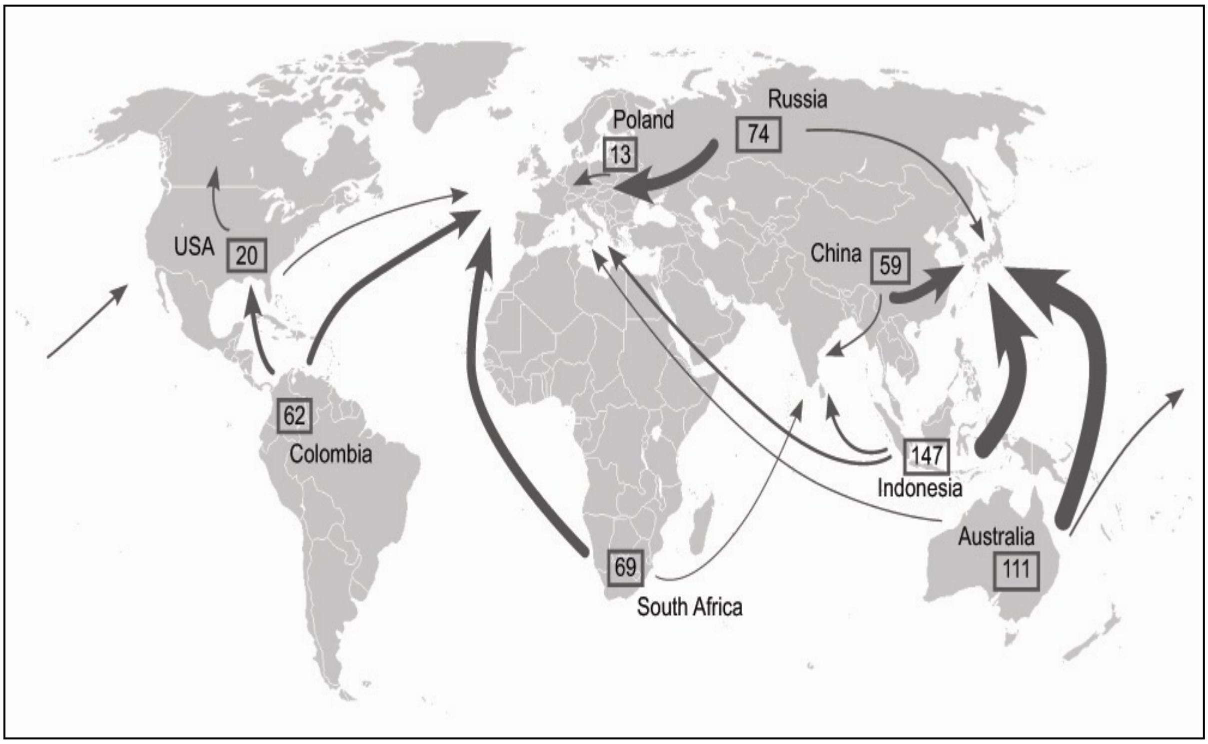
The remainder of the paper is structured as follows. In Section 2 we present descriptive analysis from which we derive testable hypotheses. Section 3 introduces the main method of analysis, Johansen Cointegration methodology, and analyzes route-specific, intra-basin, and global steam coal market integration. It also discusses the evidence on market integration. Section 4 summarizes the main findings, and suggests topics for further research.

2 Data and Hypotheses

2.1 A brief geography of international steam coal markets

International seaborne coal trade developed rapidly in the 1970s and has increased manifold since. In 2008, a total of 1.875 million tonnes (mt) of steam, coking and hard coal were traded of which about 90% account for seaborne trade, i.e. international trade across the basins. International steam coal trade amounted to 676 mt (that is 13.5% of total steam coal production) of which more than 32% was seaborne steam coal trade (IEA, 2009). Indonesia, Australia, Russia, Colombia and South Africa account for three quarters of all exports. Steam coal imports in the Asian-Pacific region in 2008 represent more than half of total steam coal trade. Another third of total world trade was received by the European market whilst the North and Latin American markets only imported 8% of total internationally traded volumes. The main international trade routes are Indonesia to Asia (149 mt), Australia to Asia (135 mt), China to Asia (42 mt), South Africa to Europe (38 mt), Colombia to Europe (30 mt), Colombia to North America (26 mt), and Indonesia to Europe (16 mt). Hence, the main trade is still taking place within the Atlantic and Pacific basins, respectively (Figure 1).

Figure 1: International steam coal trade



Source: IEA, 2009.

2.2 Data

In this section we perform a descriptive analysis of steam coal prices, freight rates, and the prices of residual fuel oil. The results motivate the remainder of our analysis. We present descriptive statistics and a principal component analysis (PCA), from which we derive three main testable hypotheses. We use weekly time series data on CIF and FOB prices as well as on a number of freight rates between major export and import locations for steam coal provided by Platts.[6] For the longest available time series our data ranges from December 2001 until August 2009, about 400 observations per time series in some cases. However, given a number of changes in coverage during the sample period, the length of the individual series varies considerably. In order to investigate the role of logistics of international seaborne steam coal trade we use the corresponding price for residual fuel oil (used to fuel ships) for each region. Given the loose integration of the domestic U.S. market we do not consider U.S. coal prices (Bachmeier and Griffin, 2006). In addition, including several available local U.S. prices would introduce a large amount of heterogeneity.

Tables 1 and 2 provide an overview of our data set. Table 1 reveals substantial heterogeneity in the characteristics of coal prices, in particular FOB prices, and also shows uneven coverage for the various price variables.

[6] The price data are collected by interviewing "trusted" traders, so that transparency on price formation is far from complete.

Table 1: Import and export prices in US dollars, by region

Atlantic

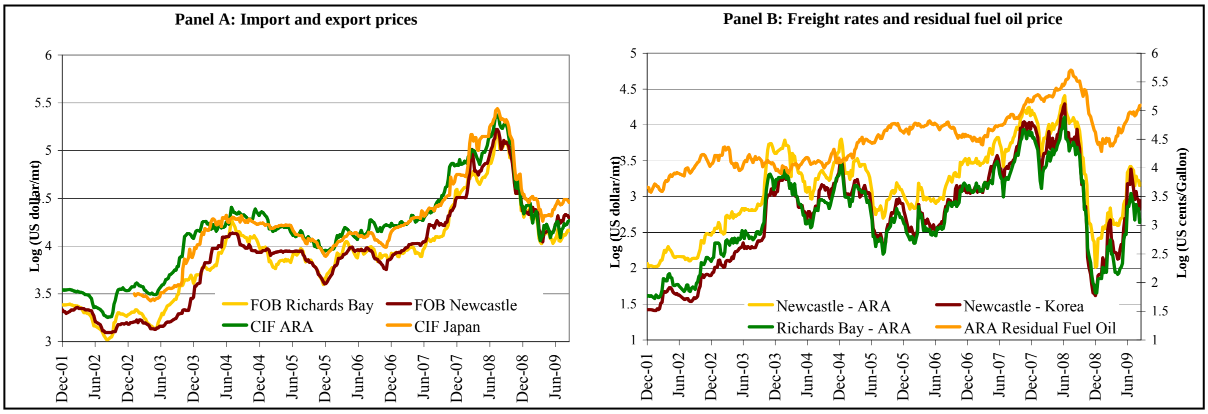
Variable	Energy value (kcal/kg)	Basis	Quality: Sulf. % (max)	Quality: Ash % (max)	From	To	Obs.	Mean	SD	Min	Max
CIF ARA	6,000	NAR	1	16	01-12-03	09-08-17	393	72.11	37.73	25.90	218.00
FOB Bolivar	6,300	GAR	0.8	9	01-12-03	09-08-17	393	58.11	30.47	22.50	179.00
FOB Bolivar	6,450	GAR	0.8	9	05-08-29	09-08-17	204	73.74	33.40	39.25	179.75
FOB Maracaibo	7,000	GAR	0.8	7	05-08-29	07-04-02	82	60.05	4.26	50.40	65.40
FOB Richards Bay	6,000	NAR	1	16	01-12-03	09-08-17	393	56.43	30.66	20.50	177.00
Poland Baltic	6,300	GAR	0.8	15	05-08-29	09-08-17	204	81.08	36.88	44.00	192.00
Russian Baltic	6,400	GAR	1	16	05-08-29	09-08-17	204	79.93	36.89	40.00	190.00

Pacific

Variable	Energy value (kcal/kg)	Basis	Quality: Sulf. % (max)	Quality: Ash % (max)	From	To	Obs.	Mean	SD	Min	Max
CIF Japan	6,080	NAR			03-01-06	09-08-17	339	79.42	41.42	30.75	230.00
CIF Korea	6,080	NAR	1	17	03-07-07	09-08-17	313	77.90	38.11	31.05	210.00
Russian Pacific	6,300	GAR	0.4	15	05-08-29	09-08-17	204	82.24	39.88	42.50	195.00
FOB Qinhuangdao	6,200	GAR	0.8	10	03-02-03	09-08-17	335	69.42	39.33	25.70	207.00
FOB Kalimantan	5,900	GAR	1	15	01-01-07	09-08-17	389	51.54	26.73	21.00	165.00
FOB Kalimantan	5,000	GAR	0.8	8	07-01-01	09-08-17	136	56.23	17.57	32.75	100.00
FOB Gladstone	6,500	GAR	0.6	12	05-08-29	09-08-17	204	78.69	38.54	38.00	195.00
FOB Newcastle	6,300	GAR	0.8	13	01-12-03	09-08-17	393	57.57	33.45	22.10	185.00

Note: GAR means gross as received, NAR means net as received. The FOB Kalimantan 5900 series was extended backwards using the FOB Kalimantan 6300 series, whereas the CIF Japan Basket series was extended backwards using the CIF Japan 6300 series.

Figure 2: Evolution of import and export prices, freight rates and residual fuel oil prices



Note: All computations are based on weekly data with all variables in natural logarithms. All freight rates are for capesize vessels, except for the rate from China to Rotterdam, which is for panamax vessels. The price data for oil is from the US Energy Information Administration. Prices for steam coal and freight rates are in natural logarithms of US dollars per metric ton and for residual fuel oil in natural logarithms of US cents per gallon. ARA residual fuel oil is plotted on the right axis.

Figure 2, Panel A shows the evolution of representative steam coal import and export prices over the sample period. Coal prices move within a fairly narrow band from the beginning of the sample until spring 2007. Since then for roughly a year prices almost quadruple before decreasing precipitously. By the end of 2008 they revert to the levels seen before 2007. This mirrors the increase and subsequent fall seen in a number of commodity prices, including oil. Figure 2, Panel B depicts several freight rates, in addition to the ARA residual fuel oil price, which was obtained from the EIA together with other benchmark fuel oil rates, such as the Singapore and New York fuel oil prices. We see that while the freight rate and fuel oil series share certain similarities, they also exhibit marked differences. During several periods oil prices and freight rates move in opposite directions, e.g., between early

2005 and early 2007. Movements in freight rates are stronger, with greater changes over short periods of time than for fuel oil price.

Whereas data on freight rates covers imports to Europe quite comprehensively, trading routes to Japan and Korea are less covered (Table 2). Also, freight rates from China to Rotterdam are not available for the whole sample period. Therefore, we compute a counterfactual continuation of the series using the Baltic Exchange Dry Index (BDI)[7] for capesize vessels. Although freight rates are available for both capesize and panamax vessels[8] for a number of trading routes, we focus on capesize vessels, since the majority of international steam coal shipping uses them (Ritschel and Schiffer, 2007).

Results of testing all variables in natural logarithms for stationarity using the augmented Dickey-Fuller test are presented in Table 3.

Table 2: Freight rates in US dollars, for capesize and panamax vessels

Capesize vessels							
Variable	Series begins	Series ends	Obs.	Mean	SD	Min	Max
Colombia/Puerto Bolivar - Rotterdam	01-12-03	09-08-17	390	18.35	11.89	3.85	62.50
South Africa/Richards Bay - Rotterdam	01-12-03	09-08-17	390	18.75	11.29	4.65	61.00
Australia/Queensland - Rotterdam	01-12-03	09-08-17	389	25.19	14.51	6.30	75.25
Australia/Queensland - Japan	01-12-03	09-08-17	389	15.69	10.25	3.60	56.90
Australia/New South Wales - Rotterdam	01-12-03	09-08-17	389	27.60	15.59	7.50	82.10
Australia/New South Wales - Korea	01-12-03	09-08-17	389	20.02	13.32	4.10	73.35
Panamax vessels							
Variable	Series begins	Series ends	Obs.	Mean	SD	Min	Max
US/Mobile - Rotterdam	01-12-03	09-08-17	390	21.71	13.33	5.70	67.50
Colombia/Puerto Bolivar - Rotterdam	04-10-04	09-08-17	250	24.23	12.21	7.40	61.50
South Africa/Richards Bay - Rotterdam	01-12-03	09-08-17	390	21.25	12.01	6.35	63.00
China - Rotterdam	01-12-03	04-09-27	140	17.82	8.73	8.25	38.95
China - Rotterdam (Adjusted)	01-12-03	09-08-17	388	28.38	18.98	4.29	99.36
Australia/Queensland - Rotterdam	01-12-03	09-08-17	389	31.37	17.38	9.75	92.50
Australia/New South Wales - Rotterdam	01-12-03	09-08-17	390	31.66	17.50	10.00	93.50

Note: China - Rotterdam (Adjusted) is a counterfactual continuation of the China - Rotterdam series using the Baltic Exchange Dry Index.

[7] The BDI is obtained from Thomson Datastream.

[8] Capesize vessels have a capacity of around 150,000 metric tons (mt) of coal, while panamax vessels can transport up to around 70,000mt. Panamax vessels are constructed to just fit the Panama Canal, while capesize vessels must travel the longer routes around the Cape.

Table 3: Unit root tests: augmented Dickey-Fuller tests

	Logs of variables			First differences of logs		
Variable	Lags	Test statistic	p-value	Lags	Test statistic	p-value
CIF ARA	2	-1.524	0.522	1	-11.726	0.000
CIF Japan	2	-1.739	0.411	4	-6.271	0.000
CIF Korea	4	-2.074	0.255	3	-6.824	0.000
FOB Bolivar	6	-1.731	0.415	1	-11.899	0.000
FOB Richards Bay	2	-1.308	0.626	1	-11.880	0.000
FOB Qinhuangdao	2	-1.657	0.454	1	-9.889	0.000
FOB Kalimantan	7	-1.430	0.568	6	-6.048	0.000
FOB Gladstone	2	-1.305	0.627	1	-8.198	0.000
FOB Newcastle	2	-1.259	0.648	1	-10.763	0.000
Colombia/Puerto Bolivar - Rotterdam	4	-2.796	0.059	3	-7.568	0.000
South Africa/Richards Bay - Rotterdam	4	-2.811	0.057	3	-7.711	0.000
China - Rotterdam (Adjusted)	4	-2.846	0.052	3	-7.415	0.000
Australia/Queensland - Rotterdam	4	-2.757	0.065	3	-7.647	0.000
Australia/Queensland - Japan	4	-2.666	0.080	3	-7.956	0.000
Australia/New South Wales - Rotterdam	4	-2.670	0.079	3	-7.742	0.000
Australia/New South Wales - Korea	4	-2.667	0.080	3	-8.003	0.000
New York Residual Fuel Oil	4	-1.984	0.293	3	-8.690	0.000
ARA Residual Fuel Oil	4	-1.565	0.501	3	-8.585	0.000
Singapore Residual Fuel Oil	4	-1.959	0.305	3	-7.351	0.000

We find that all FOB and CIF coal prices are clearly integrated of order one, I(1), as are the residual fuel oil prices. However, while we find that the freight rates are also I(1), in some cases they appear to be fairly close to stationarity. This observation contradicts the assertion that freight rates are purely driven by oil prices. Instead it appears that other considerations, such as capacity constraints due to competition for shipping capacity from other dry bulk commodities also play an important role.

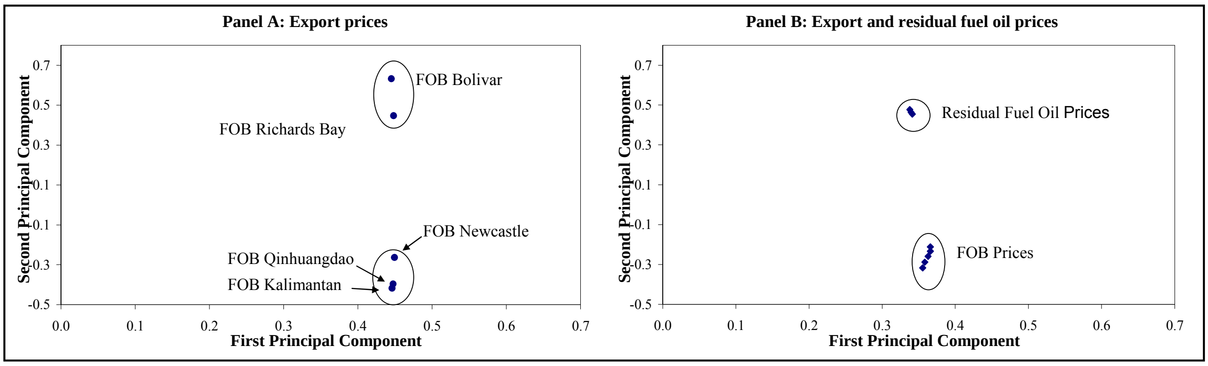
2.3 Principal components analysis (PCA) and hypotheses

In a first step of detecting relations within international steam coal markets we conduct a principal component analysis (PCA) for import prices, export prices, and freight rates. For each case we first consider coal prices and freight rates separately, before including the benchmark residual fuel oil prices. We use Jolliffe's criterion, according to which components with an eigenvalue below 0.7 should be discarded from further analysis (Dunteman, 1989). Further, we conduct the PCA for natural logs of all variables involved.

The PCA of export prices shows that one component explains around 98% of the variance in the data.[9] While all CIF prices have very similar coefficients in the first eigenvector, the second component reveals a significant difference. Although the second component only explains a small proportion of the common variance, it reveals a regional divide (Figure 3, Panel A).

[9] Due to space limitations we illustrate our results from the PCA using graphs. Tables with the numerical results are available upon request.

Figure 3: First two principal components of export prices, excluding and including residual fuel oil prices

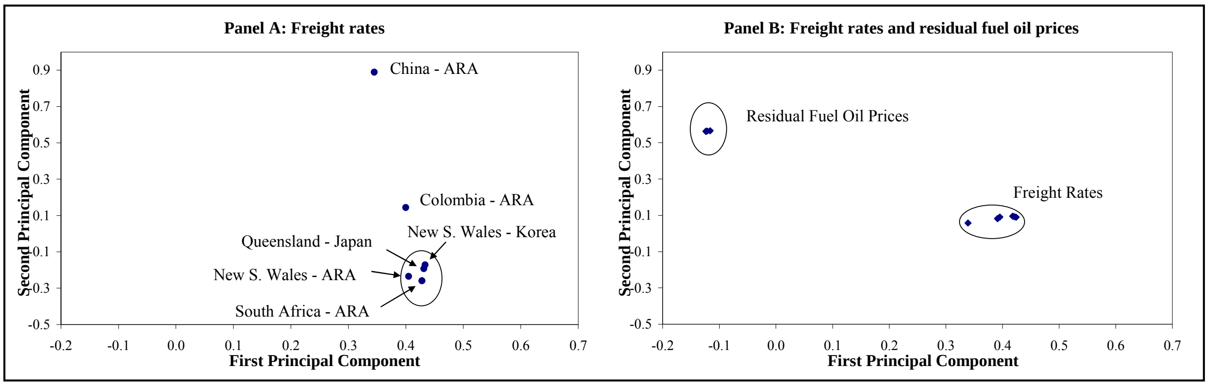


Note: All computations are based on weekly data with all variables in natural logarithms. The price data for oil is from the US Energy Information Administration.

Including residual fuel prices for the Atlantic and Pacific basins makes the second component significant and now explains 10% of the variance, while the first component explains 88%. Furthermore, while great similarity in the coefficients of the first component across fuels remains, there are now two distinct groups in the second component. Panel B in Figure 3 illustrates that the group of coal export prices and fuel prices is located similarly in one dimension, while showing distinct separation according to the second dimension. Based on this evidence we find that coal and residual fuel oil appear to share common aspects in their price formation, although a substantial gap remains which appears to be related to causes other than fuel prices. The results for import and export prices are similar.

The PCA of freight rates shows that the first component explains about 78% of the variance, while the second explains about 9%. All freight rates appear to be fairly closely related, with differences in the second component for the freight rates Colombia to ARA and China to ARA (Figure 4, Panel A), suggesting that freight rates, independent from location, may essentially be formed according to the same criteria.

Figure 4: First two principal components of freight rates, excluding and including residual fuel oil prices



Note: All computations are based on weekly data with all variables in natural logarithms. All freight rates are for capesize vessels, except for the rate from China to Rotterdam, which is for panamax vessels. The price data for oil is from the US Energy Information Administration.

Again, including residual fuel oil prices leads to a significant second component explaining about 32% of the variance, while the first component explains 53%. Freight rates form a distinctly separate group

from the group of fuel prices (Figure 4, Panel B). However, in contrast to our results for import and export prices we find that freight rates and fuel prices differ in both "significant" eigenvectors.
Thus, from our descriptive analysis we derive three testable hypotheses:

Hypothesis 1: *Prices for steam coal exports, transport and imports, respectively, are integrated to a significant degree.*

Hypothesis 2: *Coal prices and freight rates are not directly related to oil prices.*

Hypothesis 3*: International steam coal market integration is not (yet) complete.*

3 Methodology and empirical evidence

3.1 Cointegration analysis

To test these hypotheses we use cointegration analysis of prices and freight rates applying Johansen's approach based on maximum likelihood estimation which allows us to test for multiple cointegration relationships (Johansen, 1988). This enables us to draw conclusions about market integration, i.e. to evaluate both hypotheses.
We consider the vector error correction (VEC) representation of a vector process X_t :

$$\Delta X_t = \Pi X_{t-i} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \mu + \varepsilon_t \qquad (1)$$

where X_t stands for the data matrix in period t, Π denotes the long-run impact matrix, Γ_i the short-run impact matrices for lag i, μ a vector of intercept terms, and ε_t a vector of error terms.
We are primarily interested in the long-run impact matrix Π. The rank of Π determines whether the variables in X_t are cointegrated. For I(1) variables a zero rank of Π implies no cointegration relationship between variables in X_t. If Π has rank $r < k$, where k denotes the number of variables in X_t we conclude that the system is cointegrated (Hendry and Juselius, 2000; Johansen, 1988). If Π has rank $r = k$, i.e. is of full rank, the vector process X_t is stationary.
Furthermore, Π can be decomposed as follows:

$$\Pi = \alpha\beta' \qquad (2)$$

where β is the matrix of cointegrating vectors describing the long-run equilibrium of the system, and α is the corresponding matrix of adjustment parameters describing the short-run responses of each variable to deviations from equilibrium. In our analysis we determine the rank of Π by means of the trace test, and estimate β and α.

Recall that the trace statistic is computed as follows:

$$\lambda_{trace} = -T \sum_{i=r+1}^{k} \ln(1-\lambda_i) \tag{3}$$

where λ_i are the estimated eigenvalues of Π and T is the number of observations. Given that T is relatively large in our case we need to keep in mind the case described in Hendry and Juselius (2000): Even with a small λ_i, indicating the presence of a unit root or near-unit root, the large number of observations could cause us to reject the hypothesis that λ_i is zero for $i = k$. Thus, the trace test might conclude that Π has full rank and therefore the process X_t is stationary (Hendry and Juselius, 2000). For this reason Hendry and Juselius (2000, p. 24) suggest that "it is often good to approximate a near unit root by a unit root even when it is found to be statistically different from one".

Moreover, correct specification of the VEC system in terms of constants and trends is important. We find that the mean of the differenced data is greater than zero, which is consistent with $E[\Delta X_t] \neq 0$, implying a linear trend in the undifferenced data. Therefore, we allow for a linear trend in the data and a constant in the cointegration relationships (Hendry and Juselius, 2000).

To test *Hypothesis 1* we conduct the cointegration analysis in several stages. We start with a simple X_t matrix consisting of only two variables, and progressively add other variables to it. First we concentrate on pairwise comparisons of components of the supply and demand sides by considering export and import prices and freight rates separately, testing whether in each case Π is of rank $0 < r < k$, i.e. whether they are cointegrated. Such pairwise analysis allows us to compare results with the existing literature (Warell, 2006; Li, 2007), although for a different sample period and a different sampling frequency. To test *Hypothesis 2* we also include the relevant oil price, i.e. the price of residual fuel oil, which is used for powering vessels between export and import locations. This allows us to determine whether they belong to the same system.[10] For integrated fuel oil prices and components of the steam coal value chain, this implies a significant impact of logistics working through the price of fuel oil, the main driver of transport costs of the international steam coal trade.

We then go beyond the existing literature by testing *Hypothesis 3* and analyzing coal market integration in a comprehensive framework of supply and demand. We conduct a cointegration analysis of the demand and supply system, based on the premise that FOB prices together with the appropriate freight rates should be related to CIF prices in the long term. We consider systems of CIF and FOB prices and the freight rate for specific trading routes. Based on these findings we repeat the cointegration analysis using aggregated FOB prices and freight rates to facilitate a clearer interpretation of the results regarding market integration. Then we expand the analysis to the regional,

[10] Given the large number of observations we consider the 5% significance level, except where specifically mentioned. Lag lengths are determined using Akaike's Information Criterion.

i.e. intra-basin level and also test for global market integration. Finally, we estimate cointegration vectors and adjustment coefficients for the available routes to analyze both the nature of long-run relationships and short-run dynamic adjustments for each route.

3.2 Results on Hypothesis 1 (Steam coal price integration)

In the first part of our analysis we test *Hypothesis 1* by determining the rank of Π for pairs of FOB and CIF prices, as well as freight rates. This allows us to compare our results with the existing literature on steam coal market integration (Warell, 2006; Li, 2007). We then incorporate the price of residual fuel oil in our analysis to test *Hypothesis 2*.

Table 4: Determination of cointegration rank - pairwise analysis, including and excluding residual fuel oil price

			H_0: r = 0		r ≤ 1		r ≤ 2	
Variables	Obs.	Lags	λ_1	Trace statistic	λ_2	Trace statistic	λ_3	Trace statistic
Export prices								
FOB Bolivar 6300, FOB Richards Bay 6000	386	2	0.030	**13.418**	0.005	1.745	--	--
FOB Bolivar 6300, FOB Richards Bay 6000, ARA Residual Fuel	386	2	0.038	**23.654**	0.016	8.841	0.007	2.517
FOB Bolivar 6300, FOB Qinhuangdao 6200	332	2	0.024	**11.151**	0.009	3.153	--	--
FOB Bolivar 6300, FOB Qinhuangdao 6200, ARA Residual Fuel	332	2	0.047	**22.776**	0.018	6.821	0.003	0.847
FOB Bolivar 6300, FOB Kalimantan 5900	378	6	0.033	**14.872**	0.006	2.309	--	--
FOB Bolivar 6300, FOB Kalimantan 5900, ARA Residual Fuel	378	6	0.067	33.820	0.015	**7.804**	0.006	2.097
FOB Bolivar 6300, FOB Gladstone 6500	202	2	0.046	**11.332**	0.009	1.760	--	--
FOB Bolivar 6300, FOB Gladstone 6500, ARA Residual Fuel	201	3	0.088	31.674	0.052	**13.171**	0.012	2.405
FOB Bolivar 6300, FOB Newcastle 6300	386	2	0.027	**12.146**	0.004	1.686	--	--
FOB Bolivar 6300, FOB Newcastle 6300, ARA Residual Fuel	386	2	0.052	**28.028**	0.015	7.504	0.005	1.810
FOB Richards Bay 6000, FOB Qinhuangdao 6200	332	2	0.047	18.823	0.009	**2.976**	--	--
FOB Richards Bay 6000, FOB Qinhuangdao 6200, ARA Residual Fuel	332	2	0.066	30.599	0.021	**7.907**	0.003	0.977
FOB Richards Bay 6000, FOB Kalimantan 5900	378	6	0.041	18.092	0.006	**2.174**	--	--
FOB Richards Bay 6000, FOB Kalimantan 5900, ARA Residual Fuel	378	6	0.064	34.653	0.019	**9.656**	0.006	2.407
FOB Richards Bay 6000, FOB Gladstone 6500	202	2	0.082	19.115	0.009	**1.802**	--	--
FOB Richards Bay 6000, FOB Gladstone 6500, ARA Residual Fuel	200	4	0.099	35.426	0.058	**14.642**	0.013	2.608
FOB Richards Bay 6000, FOB Newcastle 6300	386	2	0.046	19.906	0.004	**1.599**	--	--
FOB Richards Bay 6000, FOB Newcastle 6300, ARA Residual Fuel	386	2	0.071	36.932	0.016	**8.318**	0.005	1.914
FOB Qinhuangdao 6200, FOB Kalimantan 5900	332	2	0.067	25.392	0.008	**2.514**	--	--
FOB Qinhuangdao 6200, FOB Kalimantan 5900, Singapore Residual Fuel	331	3	0.079	34.926	0.018	**7.729**	0.005	1.602
FOB Qinhuangdao 6200, FOB Gladstone 6500	202	2	0.044	**11.104**	0.010	2.108	--	--
FOB Qinhuangdao 6200, FOB Gladstone 6500, Singapore Residual Fuel	200	4	0.076	**29.525**	0.055	13.780	0.013	2.564
FOB Qinhuangdao 6200, FOB Newcastle 6300	332	2	0.046	19.237	0.010	**3.486**	--	--
FOB Qinhuangdao 6200, FOB Newcastle 6300, Singapore Residual Fuel	332	2	0.053	**25.097**	0.016	7.154	0.005	1.815
FOB Kalimantan 5900, FOB Gladstone 6500	202	2	0.086	19.774	0.008	**1.644**	--	--
FOB Kalimantan 5900, FOB Gladstone 6500, Singapore Residual Fuel	201	3	0.077	30.294	0.058	**14.121**	0.011	2.145
FOB Kalimantan 5900, FOB Newcastle 6300	381	3	0.060	25.363	0.004	**1.629**	--	--
FOB Kalimantan 5900, FOB Newcastle 6300, Singapore Residual Fuel	381	3	0.062	33.063	0.016	**8.489**	0.006	2.301
FOB Newcastle 6300, FOB Gladstone 6500	197	7	0.078	19.906	0.020	3.971	--	--
FOB Newcastle 6300, FOB Gladstone 6500, Singapore Residual Fuel	199	5	0.099	32.104	0.044	**11.417**	0.012	2.412
Import prices								
CIF ARA, CIF Japan	336	2	0.045	18.856	0.010	**3.418**	--	--
CIF ARA, CIF Japan, ARA Residual Fuel	335	3	0.074	31.919	0.014	**6.214**	0.005	1.540
CIF ARA, CIF Korea	309	3	0.055	21.995	0.014	4.422	--	--
CIF ARA, CIF Korea, ARA Residual Fuel	310	2	0.075	30.959	0.019	**6.928**	0.004	1.118
CIF Japan, CIF Korea	310	2	0.101	37.053	0.013	4.036	--	--
CIF Japan, CIF Korea, Singapore Residual Fuel	309	3	0.084	34.215	0.016	**7.157**	0.007	2.098
Freight rates								
Colombia-Rotterdam, South Africa-Rotterdam	384	4	0.054	28.793	0.020	7.665	--	--
Colombia-Rotterdam, South Africa-Rotterdam, ARA Residual Fuel	385	3	0.091	49.049	0.020	**12.529**	0.013	4.847
Queensland-Rotterdam, New South Wales-Rotterdam	385	3	0.105	48.838	0.015	5.974	--	--
Queensland-Rotterdam, New South Wales-Rotterdam, Singapore Residual Fuel	385	3	0.111	56.160	0.018	**11.048**	0.011	4.098
Queensland-Japan, New South Wales-Korea	384	4	0.047	24.884	0.017	6.502	--	--
Queensland-Japan, New South Wales-Korea, Singapore Residual Fuel	385	3	0.056	35.025	0.020	**12.855**	0.013	4.883

Note: Trace statistics in bold indicate significance at the 5% level. λ_i are the estimates of the eigenvalues of Π. Results are robust to choosing either New York, ARA or Singapore residual fuel oil prices for systems of prices from different basins. All freight rates are for capesize vessels, except for China-Rotterdam, which is for panamax vessels.

In all cases we observe that the estimates of λ_i, i.e. the eigenvalues of Π, are fairly close to zero, particularly λ_i for $i > 1$. We find one cointegration relationship at the 5% level in almost all cases, with the exception of the FOB Bolivar price which is not cointegrated with any of the other FOB prices. This might be due to about half of Colombia's exports going to the U.S. There is also no evidence of a cointegration relationship between FOB Qinhuangdao and FOB Gladstone. This contradicts our finding that FOB Qinhuangdao and FOB Newcastle are cointegrated so that according to the trace test, one Australian export price appears to be cointegrated with FOB Qinhuangdao while the other does not. However, for FOB Gladstone the available sample period is much shorter (ranging from mid-2005 to mid-2009) than for other FOB prices considered in our analysis. Another factor is the Chinese government's significant restrictions on coal exports as a result of a security of supply policy (Minchener, 2007). Thus, the available sample for FOB Gladstone covers the period when the Chinese export price was no longer solely determined by international demand. Hence, a combination of data availability and policy intervention on exports potentially explains this result.

Finally, the results of the trace test suggest that FOB Gladstone and FOB Newcastle are both stationary, contradicting the findings from the ADF test. We observe that for this case $\lambda_2 = 0.02$, with the small size of λ_2 indicating the presence of either a near-unit root or a unit root in X_t (Hendry and Juselius, 2000). Comparing the results for the other export prices we observe that λ_2 is in line with the size of the corresponding eigenvalues for other price pairs, and the test statistic is just large enough for the trace test to reject the hypothesis of cointegration. Given the evidence from both the ADF test and the size of the eigenvalue, we conclude that the pair FOB Gladstone and FOB Newcastle are cointegrated of order one.

The analysis of cointegration ranks of pairs of import prices (Table 4) reveals a similar pattern. There is one cointegration relationship between CIF ARA and CIF Japan at the 5% level. For the pairs CIF ARA-CIF Korea and CIF Japan-CIF Korea Π has full rank at the 5% level in each case, again contradicting our finding of non-stationarity from the Dickey-Fuller tests. However, when inspecting λ_2 for each pair of import prices we observe that they are similar in all cases, so that again, in conjunction with evidence from ADF testing we conclude that all import prices appear to be cointegrated of order one.

Our results for freight rates are more ambiguous. We typically find that Π has full rank for the respective pairs of freight rates, although the estimated eigenvalues of Π are in line with those for coal prices.[11] However, ADF tests for freight rates indicate a certain proximity to stationarity, so that evidence from univariate unit root testing is not as strong as in the case of coal prices. Nevertheless, since we still find that the ADF shows non-stationarity and that eigenvalues are similar to those for coal prices, we conclude that the large number of available observations for all freight rates leads to the case described in Hendry and Juselius (2000), where the trace statistic reaches the size necessary

[11] We do not include all possible pairs of freight rates for clarity of presentation. Results for the remaining pairs are comparable to those presented in Table 4.

for the conclusion of stationarity despite evidence for non-stationarity. Therefore, we again conclude that the pairs of freight rates are cointegrated of order one.

The findings on FOB prices partially confirm Li's (2007) result, who analyzes integration of monthly FOB prices vis-à-vis the South African FOB price. The main differences are that we do not detect integration of South African and Colombian export prices, whereas we do find integration between the South African and Indonesian prices. Comparability of results is, however, restricted by frequency of the data used and the different sample periods covered. In addition, Li's analysis is centered around the South African price. On the import side we confirm Warell's (2006) result of integration between European and Japanese CIF prices for the sample period starting in 2001.

3.3 Results on Hypothesis 2 (The role of oil prices in transport)

We next evaluate *Hypothesis 2* following a similar approach suggested by Siliverstovs et al. (2005). We add the relevant fuel oil price to the pairs of FOB and CIF prices, as well as freight rates to test whether oil prices belong to the same price system as coal prices and freight rates.[12] If we find that the added fuel oil price does not add cointegration relationships, we conclude that the oil price does not belong to the same system. As shown in Table 4 we conclude that adding the fuel price does not increase the number of cointegration relationships in most cases. However, we do find that including the fuel price increases the cointegration rank for the pairs FOB Bolivar-FOB Kalimantan and FOB Bolivar-FOB Gladstone. This may indicate that pricing for FOB Bolivar, which we did not find to be integrated with other export prices, is more strongly tied to the price of oil. We conclude that the oil price may be related to the prices of coal and to freight rates to some extent, but is not part of the long-run equilibrium relationships formed by coal prices and freight rates in any consistent fashion.

Summarizing our findings for *Hypothesis 2* we have sufficient evidence to accept it as true, confirming the result by Bachmeier and Griffin (2006) on a more global level, who find no integration between coal and oil markets in the U.S. Thus, we omit oil prices from further analysis.

3.4 Results on Hypothesis 3 (Global market integration)

Having found that our results are largely in line with the existing literature on coal market integration when using a comparable approach (although for different sample periods and sampling frequency) we now extend our analysis beyond the existing literature by taking a systemic view of integration in the steam coal market. We thus now focus on analyzing the extent of market integration in depth. The remainder of our analysis is based on the notion that for each trading route CIF prices should directly relate to a combination of FOB prices and freight rates in the long term, with CIF prices representing the demand side of the market and the combined FOB prices and freight rates representing the supply

[12] We consider three relevant prices: New York, ARA, and Singapore residual fuel oil. We add the regionally relevant price to each collection of coal prices or freight rates, e.g., for the pair of FOB Qinhuangdao and FOB Kalimantan, both of which are Pacific basin prices, we add the Singapore residual fuel oil price. When it is unclear which fuel oil price may be the relevant one, i.e. when our coal prices are from different regions, we check our results for robustness by using all the other fuel oil prices. For the most part our results are robust to the inclusion of any of the three residual fuel oil prices. We also include the WTI crude oil price as a robustness check and confirm the results.

side. This approach allows us to consider route-wise regional and global integration of steam coal markets, and is novel in the existing literature on coal market integration**.**

We apply Johansen's cointegration test to a different data matrix X_t in (1), which now consists of a CIF price, an FOB price, and a freight rate for each route. If routes are integrated a cointegration relationship between the three variables should exist. We expect individual routes to be cointegrated. Finding that multiple trading routes are cointegrated would add evidence that the global steam coal trade is taking place in an integrated marketplace. However, a caveat is that the limited availability of data on freight rates particularly constrains our analysis of price formation in the Pacific basin.

Our results support integration of a number of routes to ARA at the 5% level, although we find that vector processes X_t for the routes Colombia to ARA and Newcastle to ARA and both routes to Asia appear to be stationary.

Table 5: Determination of cointegration rank - joint analysis

Variables	Obs.	Lags	H_0: r = 0 λ_1	H_0: r = 0 Trace statistic	r ≤ 1 λ_2	r ≤ 1 Trace statistic	r ≤ 2 λ_3	r ≤ 2 Trace statistic
Atlantic basin								
CIF ARA, FOB Bolivar 6300, Freight Rate (FR) Colombia-Rotterdam	382	6	0.086	54.560	0.036	20.213	0.016	6.218
CIF ARA, FOB Richards Bay 6000, FR South Africa-Rotterdam	384	4	0.093	51.936	0.027	**14.621**	0.011	4.132
CIF ARA, FOB Qinhuangdao 6200, FR China-Rotterdam	327	5	0.133	60.132	0.027	**13.290**	0.013	4.270
CIF ARA, FOB Gladstone 6500, FR Australia/Queensland-Rotterdam	200	4	0.113	34.914	0.035	**10.984**	0.019	3.760
CIF ARA, FOB Newcastle 6300, FR Australia/New South Wales-Rotterdam	386	2	0.067	48.178	0.036	21.215	0.018	6.873
Pacific basin								
CIF Japan, FOB Gladstone 6500, FR Queensland-Japan	200	4	0.137	46.828	0.061	17.373	0.023	4.720
CIF Korea, FOB Newcastle 6300, FR New South Wales-Korea	308	4	0.102	49.310	0.029	16.282	0.023	7.199

Note: Trace statistics in bold indicate significance at the 5% level. λ_i are the estimates of the eigenvalues of Π.

Again, we believe that our previous argument applies for the routes Colombia to ARA and Newcastle to ARA, as well as for the route Newcastle to Korea. λ_2 for Colombia to ARA and Newcastle to ARA is almost identical to λ_2 for the route Gladstone to ARA, which is found to be cointegrated. The only difference is that we have a larger number of observations for the routes Colombia to ARA and Newcastle to ARA, which raises the trace statistic beyond the 5% critical value. λ_2 for the route Newcastle to Korea is slightly larger than λ_2 for South Africa to ARA. Based on this comparison we conclude that the evidence points to integration of routes.

We next aggregate export prices and freight rates for each route and test for cointegration of the respective routes. All aggregated variables are non-stationary, and we are now testing pairwise relationships for each route. We thus have the CIF price representing the demand side of the market, while the combined FOB price and freight rate represent the supply side of the market for each route. The results are clearer than when separating the supply side into export prices and freight rates.

Table 6: Determination of cointegration rank - joint analysis of aggregated routes

Variables	Obs.	Lags	H_0: r = 0 λ_1	Trace statistic	r ≤ 1 λ_2	Trace statistic
Atlantic basin						
CIF ARA, FOB Bolivar 6300+FR Colombia-Rotterdam	381	7	0.058	26.393	0.009	**3.602**
CIF ARA, FOB Richards Bay 6000+FR South Africa-Rotterdam	386	2	0.087	37.674	0.006	**2.446**
CIF ARA, FOB Qinhuangdao 6200+FR China-Rotterdam	325	7	0.031	**13.829**	0.011	3.722
CIF ARA, FOB Gladstone 6500+FR Australia/Queensland-Rotterdam	202	2	0.068	16.603	0.011	**2.280**
CIF ARA, FOB Newcastle 6300+FR Australia/New South Wales-Rotterdam	386	2	0.058	25.737	0.007	**2.572**
Pacific basin						
CIF Japan, FOB Gladstone 6500+FR Australia/Queensland-Japan	200	4	0.077	18.984	0.014	**2.867**
CIF Korea, FOB Newcastle 6300+FR Australia/New South Wales-Korea	310	2	0.072	28.958	0.019	5.872

Note: Trace statistics in bold indicate significance at the 5% level. λ_i are the estimates of the eigenvalues of Π.

We find that all routes to Europe and Asia are cointegrated at the 5% level with the exception of the route China to ARA. This result is expected given the Chinese export restrictions discussed above, so that traders are constrained in using arbitrage to equilibrate prices (Minchener, 2007). Further, for the Newcastle to Korea route we still find the contradictory result of stationarity at the 5% level. When considering λ_2 for this route we observe that it is somewhat larger than λ_2 for the other routes, resulting in a larger value for the trace statistic which is clearly above the critical value. While we still tend to conclude that the route is cointegrated, we are slightly less confident about doing so in this particular case. However, we still estimate the VEC system based on a cointegration rank of one (Hendry and Juselius, 2000).

Having confirmed route-wise integration for most cases we test for regional and global integration of steam coal markets.

Table 7: Determination of cointegration rank - basin-wise and inter-basin analysis

Variables	Number of variables in system	Obs.	Lags	H_0: r ≤ 2 λ_3	Trace statistic	r ≤ 3 λ_4	Trace statistic	r ≤ 4 λ_5	Trace statistic	r ≤ 5 λ_6	Trace statistic
Atlantic system	6	200	2	0.106	49.846	0.065	**27.339**	0.046	13.859	0.022	4.374
Pacific system	4	201	3	0.049	**15.384**	0.026	5.294	--	--	--	--
Global system	10	200	2	0.243	200.337	0.187	144.703	0.164	103.218	0.127	**67.304**

Note: Trace statistics in bold indicate significance at the 5% level. λ_i are the estimates of the eigenvalues of Π. The Atlantic system contains the variables CIF ARA, FOB Bolivar 6300+FR Colombia-Rotterdam, FOB Richards Bay 6000+FR South Africa-Rotterdam, FOB Qinhuangdao 6200+FR China-Rotterdam, FOB Gladstone 6500+FR Australia/Queensland-Rotterdam, and FOB Newcastle 6300+FR Australia/New South Wales-Rotterdam. The Pacific system contains the variables CIF Japan, CIF Korea, FOB Gladstone 6500+FR Queensland-Japan, and FOB Gladstone 6500+FR Queensland-Japan. The Global System combines all variables from the Atlantic and Pacific systems.

We find that the routes within the Atlantic and the Pacific basins have multiple cointegration relationships. For the system of routes to the Atlantic basin we find three relationships, and for the Pacific basin we find two. From this we conclude that coal markets are integrated regionally. We then consider whether all available routes are cointegrated globally. When combining the variables from the two systems we find five cointegration relationships. From this we conclude that the international steam coal trade takes place in basin-wise and globally integrated markets. Although the exchange of coal between the Atlantic and Pacific basins is limited in terms of quantity (EPRI, 2007), the interaction is sufficient to cause inter-basin integration of steam coal markets.

Based on the results presented in Table 6 we estimate cointegration vectors and adjustment coefficients for the various routes using the disaggregated specification from Table 5 which allows us to disentangle relative effects of export prices and freight rates. We perform the estimation assuming one cointegration relationship for the routes China to ARA and New South Wales to Korea. We expect weaker or insignificant results for the estimated adjustment parameters for these routes, which would confirm our findings of incomplete integration. Hence, we examine the internal working of coal pricing systems.

Table 8: VEC estimation

CIF ARA, FOB Bolivar, FR Colombia/Puerto Bolivar-ARA (CI Rank = 1)		
Cointegrating vector (coefficient on ln(CIF ARA) normalized to 1)		
Beta	Coefficient	p-value
ln(CIF ARA)	1.000	n/a
ln(FOB Bolivar)	-0.450	0.000
ln(FR Puerto Bolivar-Rotterdam)	-0.521	0.000
Adjustment coefficients		
Alpha	Coefficient	p-value
D(ln(CIF ARA))	-0.045	0.000
D(ln(FOB Bolivar))	-0.035	0.004
D(ln(FR Puerto Bolivar-Rotterdam))	0.128	0.000
Lags	6	
Observations	382	

CIF ARA, FOB Gladstone, FR Australia/Queensland-ARA (CI Rank = 1)		
Cointegrating vector (coefficient on ln(CIF ARA) normalized to 1)		
Beta	Coefficient	p-value
ln(CIF ARA)	1.000	n/a
ln(FOB Gladstone)	-0.374	0.003
ln(FR Queensland-Rotterdam)	-0.694	0.000
Adjustment coefficients		
Alpha	Coefficient	p-value
D(ln(CIF ARA))	-0.058	0.000
D(ln(FOB Gladstone))	-0.031	0.019
D(ln(FR Queensland-Rotterdam))	0.049	0.093
Lags	4	
Observations	200	

CIF ARA, FOB Richards Bay, FR South Africa/Richards Bay-ARA (CI Rank = 1)		
Cointegrating vector (coefficient on ln(CIF ARA) normalized to 1)		
Beta	Coefficient	p-value
ln(CIF ARA)	1.000	n/a
ln(FOB Richards Bay)	-0.664	0.000
ln(FR Richards Bay-Rotterdam)	-0.340	0.000
Adjustment coefficients		
Alpha	Coefficient	p-value
D(ln(CIF ARA))	-0.123	0.000
D(ln(FOB Richards Bay))	-0.113	0.000
D(ln(FR Richards Bay-Rotterdam))	0.200	0.003
Lags	4	
Observations	384	

CIF ARA, FOB Newcastle, FR Australia/New South Wales-ARA (CI Rank = 1)		
Cointegrating vector (coefficient on ln(CIF ARA) normalized to 1)		
Beta	Coefficient	p-value
ln(CIF ARA)	1.000	n/a
ln(FOB Newcastle)	-0.384	0.000
ln(FR New South Wales-Rotterdam)	-0.608	0.000
Adjustment coefficients		
Alpha	Coefficient	p-value
D(ln(CIF ARA))	-0.043	0.000
D(ln(FOB Newcastle))	-0.027	0.005
D(ln(FR New South Wales-Rotterdam))	0.052	0.036
Lags	2	
Observations	386	

CIF ARA, FOB Qinhuangdao, FR Qinhuangdao-ARA (CI Rank = 1)		
Cointegrating vector (coefficient on ln(CIF ARA) normalized to 1)		
Beta	Coefficient	p-value
ln(CIF ARA)	1.000	n/a
ln(FOB Qinhuangdao)	0.184	0.394
ln(FR Qinhuangdao-Rotterdam)	-1.525	0.000
Adjustment coefficients		
Alpha	Coefficient	p-value
D(ln(CIF ARA))	-0.014	0.000
D(ln(FOB Qinhuangdao))	-0.008	0.011
D(ln(FR Qinhuangdao-Rotterdam))	0.042	0.000
Lags	5	
Observations	327	

CIF Japan, FOB Gladstone, FR Australia/Queensland-Japan (CI Rank = 1)		
Cointegrating vector (coefficient on ln(CIF Japan) normalized to 1)		
Beta	Coefficient	p-value
ln(CIF Japan)	1.000	n/a
ln(FOB Gladstone)	-0.776	0.000
ln(FR Queensland-Japan)	-0.298	0.000
Adjustment coefficients		
Alpha	Coefficient	p-value
D(ln(CIF Japan))	-0.093	0.000
D(ln(FOB Gladstone))	-0.065	0.012
D(ln(FR Queensland-Japan))	0.198	0.013
Lags	4	
Observations	200	

CIF Korea, FOB Newcastle, FR Australia/New South Wales-Korea (CI Rank = 1)		
Cointegrating vector (coefficient on ln(CIF Korea) normalized to 1)		
Beta	Coefficient	p-value
ln(CIF Korea)	1.000	n/a
ln(FOB Newcastle)	0.472	0.183
ln(FR New South Wales-Korea)	-1.766	0.000
Adjustment coefficients		
Alpha	Coefficient	p-value
D(ln(CIF Korea))	-0.012	0.000
D(ln(FOB Newcastle))	-0.009	0.000
D(ln(FR New South Wales-Korea))	0.023	0.013
Lags	4	
Observations	308	

We first analyze the relative contribution of export prices and freight rates to the equilibrium relationship for the various routes. Then we describe the speed of adjustment to the long-run equilibrium relationship.

In almost all cases our estimates of the coefficients of β in (2) are highly significant. The exceptions are the China to ARA and Newcastle to Korea routes, which we expect given the lack of cointegration we find for China to ARA and the somewhat ambiguous result on integration for Newcastle to Korea. In the cases of identified normalized cointegrating vectors, their respective coefficients have the same sign across routes. Thus, the basic setup of the equilibrium relationship is identical for each route. However, the relative importance of export prices and freight rates differs by route; the weight of the freight rate increases with the growing distance between export and import locations.

The respective adjustment coefficients have the same signs in all and are highly significant in most specifications. The coefficients on CIF and FOB prices are always negative, although the coefficients on CIF prices are always larger in absolute value, whereas the coefficients on freight rates are always positive. This is consistent with our observation that CIF and FOB prices move together, driven by demand from import locations.

Our estimates of the adjustment coefficients indicate that CIF prices adjust back to the equilibrium level in case of a deviation from equilibrium. FOB prices move in the same direction as CIF prices, slowing down the adjustment process. Freight rates have positive adjustment coefficients, which in many cases are larger in absolute value than those of coal prices, indicating that freight rates also move the system back to equilibrium and that they do so quite strongly.

However, while the signs of the corresponding coefficients are identical, their magnitudes differ substantially across routes. The coefficients for the route South Africa to ARA are largest in absolute value while the routes China to ARA and Newcastle to Korea are smallest, but highly significant. This implies that the route South Africa to ARA returns to equilibrium the quickest, which seems reasonable since it is the most commercialized route and active arbitrage is taking place.

The results for China to ARA and Newcastle to Korea imply that these systems only slowly revert to long-run equilibrium. This is in line with our earlier finding of no cointegration, at least for the case of China, where the Chinese government's restrictions on coal exports weaken the influence of market forces and prevent a quick adjustment to equilibrium. Overall the different speeds at which the individual routes return to the long-run relationship indicate that there is still significant international market segmentation.

3.5 Discussion

We conclude that the evidence mostly favors the hypothesis of global integration of the steam coal market, but we find signs that integration is not yet complete. While the FOB price for Colombia is not cointegrated with any of the other export prices, we find that the route Colombia to ARA is integrated with a large adjustment coefficient. This suggests that the freight rate is mostly responsible for equilibrating this particular market and for creating an integrated shipping route, while the Colombian export price itself may still have to complete the integration process in the supply side of the international market for steam coal.

We also find evidence that government policy has caused some disintegration from the global market in the case of China. Starting in 2004, the Chinese government gradually moved from supporting coal exports through tax credits to constraining them through ever-tightening export restrictions (Minchener, 2007). The result of these policy-induced restrictions has been a disconnect from the global market as exemplified by a lack of cointegration of FOB Qinhuangdao with FOB Gladstone, one of the Australian prices which constitute the benchmark price for coal traded in the Pacific basin. We also find that the route China to ARA is not integrated. Even if we suppose that the China to ARA route is weakly integrated, our estimates of the adjustment coefficients show that once disturbed, it is slow in adjusting back to long-run equilibrium. Our interpretation of this finding is that export restrictions have weakened the forces of arbitrage on the China-ARA route so that Chinese suppliers of steam coal are constrained in reacting to information about changed market conditions at the same speed as less-encumbered suppliers of coal (such as South African ones) are able to do.

Further evidence of incomplete integration of the global market is the significant difference between adjustment coefficients for the respective trading routes. Different routes adjust at significantly different speeds, showing that substantial rigidities remain in the international steam coal market, even though prices are generally integrated.

While identifying some evidence of incomplete integration and rigidities in the international steam coal market, we conclude that the main evidence favors global steam coal market integration. In addition, our confirmation of *Hypothesis 2* shows that the coal market may be integrated within itself, but it does not appear to be integrated with the larger market for fossil fuels (Bachmeier and Griffin, 2006).

4 Conclusions

In this paper we analyze the integration of the seaborne international steam coal trade using a richer data set than the existing literature in terms of scope and frequency. Following a descriptive analysis we derive three testable hypotheses. Our first hypothesis is that international steam coal prices are directly related to each other, and our second hypothesis is that the prices of steam coal and freight rates for transportation are not integrated with the price of oil. This implies that logistics do not enter the pricing system for coal through the main driver of shipping costs, but in a more complex manner. Additionally, our third hypothesis is that global markets for steam coal are not yet completely integrated when taking into account systems of supply and demand.

We use a detailed multivariate cointegration analysis of the system of demand and supply of steam coal consisting of CIF prices on the demand side and FOB prices and freight rates on the supply side. From our analysis of the various components of the demand and supply sides separately we can partially confirm the findings in the existing literature. We find that the majority of export prices are cointegrated, with the two notable exceptions of Colombian prices with any of the other export prices, and Chinese exports with exports from one Australian location, Gladstone. We also confirm results about the integration of import prices from the existing literature (Warell, 2006).

We conclude that the price of (residual fuel) oil does not belong to the same system of either coal prices or freight rates, confirming our hypothesis that logistics affect the steam coal trade in more complex ways than simply through the price of oil.

With FOB prices and freight rates aggregated, we test the integration of the demand and supply sides of the coal market for each route, by basin and globally. This analysis is novel compared to the existing literature. We find significant integration of the international trade in steam coal, with the notable exception of the China to ARA route, and contradictive evidence for the New South Wales to Korea route. Once we expand our analysis to the regional and global levels we find significant cointegration of both the regional and global markets.

Having addressed the existence of integration we analyze the setup of the long-term equilibrium and short-term dynamics for each route. We find similarity for both long-term structure and short-term dynamics among all integrated routes. However, we also find significant differences regarding the roles of prices and freight rates in the long-term relationship and the speed of adjustment. We conclude that while the coal market has achieved a significant amount of global integration, it still exhibits rigidities by route, with the system achieving equilibrium more rapidly on some routes than on others, both within and across basins.

We suggest that additional research should address spatial price competition, taking into account transportation limitations (e.g., Panama Canal) as well as differences in coal qualities. Furthermore, the use of steam coal mainly for electricity generation has direct repercussions for the prices of emissions allowances, at least in Europe. In addition, interfuel competition may be affected, so that adding the prices of additional fuels and emissions allowances to the analysis should extend our findings. Another fruitful avenue for further research is to analyze the precise role of logistics in the pricing of transportation costs.

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