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Price and Volatility Spillovers Across the International Steam Coal Market

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Abstract

We examine the degree of integration of the global steam coal market. Using a variety of measures, we show that the Australian market remains the dominant force in setting world coal prices, followed by Mozambique and South Africa. We find little evidence of asymmetric price and volatility transmission. In fact, most markets react to both positive and negative shocks in a symmetric manner. The coal market displays a significant degree of integration, although this effect varies over time. While China provides a major source of volatility to the global coal market, it is relatively insignificant in terms of price transmission.

Keywords: Integration; Information transmissions; Generalized VAR model; Steam coal

JEL Codes : C32, F18, F49, Q37

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1. Introduction

Steam coal (also known as thermal coal) is the most important fuel source for power generation worldwide. In 2016, for example, coal accounted for 37% of global electricity production, while the next four largest sources, i.e. gas, renewables, nuclear energy and oil, represented only 24%, 24%, 11% and 4% of the global market, respectively[1]. The importance of coal as an energy source also continues to rise. For example, the demand for steam coal in generating electricity increased from 33% in 1971 to 41% in 2013 (World Bank., 2015)[2]. Thus, despite the increased use of alternative energy sources worldwide, the percentage share of coal as an energy source has increased relative to its long-term average value.

In this paper we examine the degree of integration of the steam coal market. Many energy sector analysts and researchers consider the international coal market to be well-integrated (e.g., (Ellerman, 1995), (Humphreys and Welham, 2000); (Wårell, 2006); (Li et al., 2010a); (Smiech et al., 2016)). While there is little debate on the presence of integration in the coal market, there is only limited empirical evidence available regarding the intensity and direction of return and volatility transmission effects across the various regional coal markets, which historically have been segmented due to distances imposed by particular geographical locations. Furthermore, the question of asymmetric information transmission across markets, which is well documented in the finance literature, is still largely unexplored in this area of energy economics.

The closest contribution to ours has been provided by Papiez and Smiech (2015) who analysed the integration of the steam coal markets using weekly data spanning from October 5, 2001 to March, 28, 2014. Papiez and Smiech (2015) employed the rolling trace test to identify the level of coal markets integration. They found the relationships between the freight costs and degree of integration between markets. Particularly, in the periods when freight costs are higher the integration is weaker, while in the period when the costs are lower the integration is stronger. They also identified the main price-setters and price-takers, highlighting that their roles are changing over time. However, Papiez and Smiech (2015)

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[1] Source: World Coal Association, www.worldcoal.org/global-electricity-mix

[2] This number is based on the authors calculations using data from 169 countries, for the period from 1960 to 2014. It should be noted that there is significant variation between countries. For example, as much as 95% of electricity is generated from coal-fired power plants in Botswana and South Africa, 75% in Australia and 69% in China. On the other hand, other countries use less coal for their electricity production due to alternate sources of supply, such as from nuclear power (e.g. in France only 2% of electricity was generated from coal-fired power plants in 2014). Ninety five percent of electricity is generated from coal-fired power plants in Botswana and Mozambique, while the figure for China is 69%, and 75% for Australia.

study employs only coal prices although the intensity and dynamics of volatility spillovers can be different from level. Therefore, we augment the existing evidence on information transmission mechanism between steam coal markets using alternative empirical approaches that are employed to both prices and volatilities.

Our paper differs from other studies in the literature in the following ways. First, it provides novel evidence about both the price and volatility transmission processes across eight major international coal markets. To understand these dynamics, we apply the variance decomposition framework of Diebold and Yilmaz (2012) to weekly coal prices and volatilities in order to measure the total, directional and net-pairwise spillover indices. Second, we also use an asymmetric causality test of Hatemi-J (2011) to provide new results on the degree of asymmetry in the spillovers present in the global coal market. We augment them with a number of additional robustness tests. These statistical measures show that the Australian market remains the dominant force in setting world coal prices with little evidence of asymmetric price and volatility transmission. Consistent with previous findings, we show that the international coal market displays a significant degree of integration, although this effect varies over time due to different economic shocks and other impacts arising from technological innovation.

Finally, we provide indication regarding how our results can be used for the design of hypothetical trading strategies relying on the findings about the markets which have been identified as net-contributors and net-recipients.

The paper is organized as follows. The next Section 2 provides the overview of the steam coal market. Section 3 presents a review of the literature about integration and spillover effects in the coal market. Section 4 describes the dataset and the methodology used in our empirical analysis, while Section 5 reports the empirical results. Section 6 provides indication regarding how our findings can be used for the design of hypothetical trading strategies. Section 7 discusses the results and presents their broader economic interpretations as well as implications for international steam coal market participants. Finally, Section 8 concludes the paper.

2. Steam Coal Market Overview

Globalization and other economic and political drivers of the integration process in the coal industry began in the 1960s. Until that time, the international coal market was highly fragmented with mostly domestic production of steam coal used by households for heating. Coal was rarely exported due to high transportation costs. With significant increases in the oil price, following the Organization of Arab Petroleum Exporting Countries (OAPEC) oil embargo in the 1970s, the demand for steam coal for electricity generation increased signifiantly. Improvements in transport infrastructure also occurred around this timewith the cost of shipping declining significantly (Lundgren, 1996). All tese factors drove the increase in global demand for coal, during the period of four decades between 1965 and 2014, by more than 278% (British Petroleum, 2015).

The two largest coal producing countries worldwide are China (1844.6 Mt Million tonnes oil equivalent in 2014) and the United States (507.8 Mt Million tonnes oil equivalent in 2014), although these two markets mainly consume their own coal. The major coal exporting countries are Australia, Indonesia, Columbia and South Africa, while a number of other key countries have limited domestic production and rely on coal imports. These markets include the key industrialised export-based economies of Japan, South Korea and Taiwan as well as some western European countries.

International trading activity in coal is clearly divided into two geographical centres based around the Atlantic and Pacific regions. The trade pattern within these two regions is based on variation in domestic production and freight costs (Wårell (2006)). The Atlantic market includes Northwest Europe, South Africa, Colombia and Russia, where Russia is the largest exporter. The cost, insurance and freight (cif) ARA price (Amsterdam, Rotterdam, Antwerp) is the benchmark coal price for European importers in the Atlantic basin market, while free on board (fob), meaning that the buyer takes delivery of shipped goods once the goods leave the supplier's shipping dock, is used elsewhere. For example, key export prices are fob Puerto Bolivar (Colombia), fob Richards Bay (South Africa) and fob Baltic ports (Russia). Papiez and Smiech (2015) found that price movements appear to be initiated mainly by the Atlantic market with pricing from the ARA ports being of particular importance.

Within the Pacific market the largest importing countries are Japan, South Korea, China, Taiwan and India, whereas Australia, Indonesia, Vietnam, China and Russia are the main exporters. While India is technically not located on the Pacific rim, its suppliers however are. South Africa is uniquely placed geographically to supply both the Atlantic and Pacific basin markets. The main benchmark importing price is cif South China, while the main benchmark exporting price in the Pacific market is fob Newcastle-Australia (Zaklan et al. (2012a) and Papiez and Smiech (2015)).

3. Integration and Spillovers in Coal Market

The existence of an integrated commodity market is implied through the economic theory of the law of one price. Originally, Heckscher (1916) argued that trade-based transaction costs, arising from spatial separation of counter-parties, can lead to deviations from the law of one price (i.e. price divergence). The basic research framework for analysis of non-linear price convergence is presented in Section 3. This investigation is motivated by a number of papers including Taylor et al. (2001); Sarno et al. (2004) and Apergis and Lau (2015). The price differential creates an arbitrage opportunity for the same, and to some extent substitutable, good (e.g. steam coal of various qualities). Thus, lower-priced goods will be transported to another region and sold for a higher price (inclusive of all transaction and transportation costs). In equilibrium, the prices of the same good at different locations will converge to a single price (or at least to a similar price level).

Note that within this framework, the trade only occurs on condition that price difference, or profit, generated from the arbitrage activities can cover the transaction cost (see Taylor et al. (2001)). For example, consider a case where Australia ships steam coal to Europe and Japan. If the law of one price holds, the price differential between Europe and Japan should be equal to the difference in shipping costs between Australia-Europe and Australia-Japan Wårell (2006).

Numerous empirical studies have applied the theoretical non-linear version of the law of one price to allow for differences in the degree of income and price convergence (for example, see Akhmedjonov et al. (2013); Lau et al. (2012); Akhmedjonov and Lau (2012); Lau et al. (2012); Suvankulov et al. (2012)). Other notable recent studies include Akhmedjonov et al. (2013), who uses Exponential Smooth Auto Regressive Augmented DickeyFuller (ESTAR-ADF) unit root tests to investigate the unconditional income convergence across Russian regions, and finds evidence of inter-regional inequalities. Another example is Lau et al. (2012), who propose a new theoretical model to investigate if there is income convergence across the provinces of China. Their study applies a non-linear panel unit root test of Exponential Smooth Auto-Regressive Augmented Dickey-Fuller (ESTAR-ADF) unit root test to empirically test the conditional convergence hypothesis in China from 1952 to 2003 and find that the number of converging provinces decreases in the post-reform period.

A similar approach is adopted by Akhmedjonov and Lau (2012), who investigate the pattern of price convergence in Russian energy markets, comprising diesel, gasoline, electricity and coal, from January 2003 to October 2010, over 83 Russian regions. Given the geographical scale of Russia, and variation in transport and infrastructure costs, it is not surprising that they find evidence of segmentation. Nonetheless, the unequal distribution of energy reserves and limited cross-border transmission capacity across different regions, creates a complex set of pricing distortions, with the coal price correctly converging in only 37% of the Russian regions.

However, another obstacle to regional convergence is local protectionism. For example, Young (2000) argues that there is increasing local protectionism in China, as provinces attempt economic adjustment driven by national policy change (e.g. the decision not to use local coal that may be more polluting than imported coal).

Market structure is another factor that affects the degree of market integration. (Wårell, 2006) suggests that since the coal industry has experienced a number of mergers and acquisitions, this in turn may lead to larger and more monopolistic corporations being able to manipulate and control prices (Regibeau, 2000). Mergers and acquisitions may result in barriers to entry, price discrimination and collusion; therefore price convergence across markets is invalid because the law of one price does not hold. However one may also argue that mergers and acquisitions drive productivity improvement in the form of cost-cutting, and this potential increase in profit may encourage price convergence.

Market structure is another factor that affects the degree of market integration. Wårell (2006) suggests that since the coal industry has experienced a number of mergers and acquisitions (see e.g. Regibeau (2000), among others), the establishment of these larger corporations may lead to less competition in the global market. Given the scale and scope economies available to these large, merged corporations, this may also lead to infrastructure based barriers to entry, price discrimination and collusion. Therefore, the conclusion on price convergence across markets is biased, and potentially misleading in terms of policy outcomes, because the law of one price does not hold. However, one may also argue that mergers and acquisitions drive productivity improvement in the form of cost-cutting and that this increase in profit margin may encourage price convergence.

The existing empirical evidence concerning the scope (and to some extent scale) of coal market integration is somewhat mixed. Li et al. (2010a) performed a cointegration analysis using monthly FOB coal prices in the period January 1995 - July 2007 and concludes that the global steam coal market is well integrated. However, Zaklan et al. (2012b) applied a similar cointegration analysis to the steam coal market using export and import steam coal prices, and freight rates for the period December 2001 to August 2009, and find that the steam coal market is not fully integrated. The analysis by Wårell (2006) of the international coal market, also found evidence of integration between Europe and Japan, for the period

1980 to 2000, using cointegration techniques.

Wårell (2006) also tested for the presence of a single international market for the steam coal industry and concluded that there was no long-run cointegrating relationship between the respective price series (i.e. quarterly Cost, Insurance and Freight (CIF) import coal prices). The lack of a single market was attributed to mergers and acquisitions during the sample period. Smiech et al. (2016) investigated the relationships between steam coal prices in the Atlantic and Pacific basins using Granger causality tests. They concluded that the Pacific basin plays a dominant role in the setting of global price due to the large import demand from China, Korea and Japan.

We contribute to the energy economics literature by undertaking a more extensive analysis of the global coal market than these previous studies. Our findings reveal complex patterns of price and volatility transmission mechanisms within the global coal market. Moreover, we consider not only regional price causality, but also examine the spillover and transmission channels of price and volatility across markets using the Diebold and Yilmaz (2012) framework. This method has been previously employed in analysis of the interrelationships in the global base metal markets by Ciner (2018) and spillovers between equity and futures markets by Yarovaya et al. (2016), but to our best knowledge it has not been applied to the steam coal markets yet. Thus, a key novelty of this paper is that it is the first study to provide an empirical analysis of price and volatility spillovers and transmission mechanisms across the international coal market using this new methodology.

4. Methodology

4.1. Data

Our study employs weekly coal price index data from January 12, 2001 to December 26, 2014. We investigate price convergence and spillover effects across eight international steam coal markets located in Australia, China, Amsterdam Rotterdam Antwerp, Colombia, Russia (Baltic), Russia (Vostochny), Mozambique, and South Africa. All data are sourced from Bloomberg. Table 1 presents the summary statistics of the stem coal prices in these eight steam coal markets. Sample means, medians, maximums, minimums, standard deviations, skewness, kurtosis, and the Jarque-Bera (JB) statistic are reported. According to key statistics on the supply, transformation and consumption of all major energy resourcers provided by the International Energy Agency, the leading producers of coal are China, Australia, Russia and South Africa accounted for 44.7%, 6.6%, 5.1% and 3.4% of world total coal production in 201, respectively. It is also important to highlight that the net exporters of coal are Australia (379Mt), Russia (161Mt), South Africa (71Mt) and Mozambique (12Mt), while China (263Mt) is still net importer of coal regardless its leading role in the global production of coal[3].

The weekly price indexes for the markets ranged from \$64.538 (South Africa) to \$81.056 (China). The standard deviations range from \$28.027 (Europe) to \$41.213 (China). China is the most volatile market while Europe is the most stable market. There are also some types of nonlinear components within its Data Generating Process (DGP). Table 1 also shows a clear evidence of departures from normality (as implied by significant JB statistics).

Table 3 reports tests for the presence of a unit root (we accept the null hypothesis of a unit root at the 0.01 level of significance). We conclude that the steam coal price indexes are non-stationary. The test also indicates that a structural break occurs in late 2007 with the exception of China and the Russian Baltic. Moreover we use the Narayan et al. (2010) 2-break test, which is more powerful. The result shows that all series contain a unit root, with an exception of Australian market (see Table 4, panel A). Furthermore, because the empirical analysis is based on weekly data, Narayan and Liu (2015) show that heteroskedasticity is an issue and therefore they develop a GARCH unit root test. As data actually exhibit heteroskedasticity, we therefore carried out the test of Narayan and Liu (2015), and the result shows that all series are stationary (see Table 4, panel B).

4.2. Nonlinear Panel Unit Root Test

Numerous studies apply unit root tests to investigate market integration. For example, Fan and Wei (2006) find evidence of high integration between major Chinese goods, such as raw materials and durable goods; Ma et al. (2009) provide evidence that major energy prices are converging to their national averages in China; Suvankulov et al. (2012) investigate gasoline price convergence in Canada using nonlinear panel unit root test and find evidence that price convergence has declined significantly since July 2006; Fallahi and Voia (2015) study the stochastic convergence of per capita energy use in 25 OECD countries; Presno et al. (2014) find evidence of convergence in per capita CO2 emissions in 28 OECD countries using nonlinear unit root test.

The use of a nonlinear panel unit root test can achieve higher statistical power in comparison to a linear panel unit test if data contains non-linear elements (Lau et al., 2012) and this fact is confirmed here by the BDS test. Consider the series of interest for market i, which

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[3] Source: www.iea.org/statistics/kwes/supply/

at time t is $y(i,t)$ that is defined as follows:

$$y_{i,t} = ln(\frac{V_{i,t}}{\tilde{V_t}}) \tag{1}$$

where $V_{i,t}$ is the price index for market i at time t $(t = 1...T)$; $y_{i,t}$ is the relative price index in comparison to the average, and $\tilde{V_t}$ is the average price index across all markets at time t. Following Cerrato et al. (2011, 2013), the Data Generating Process (DGP) for the time series of interest $y_{i,t}$, can be modelled as:

$$y_{i,t} = \xi_i y_{i,t-1} + \xi_i^* y_{i,t-1} Z(\theta_i; y_{i,t-d}) + \mu_{i,t} \tag{2}$$

where

$$Z(\theta_i; y_{i,t-d}) = 1 - exp[-\theta_i(y_{i,t-d} - \chi^*)^2] \tag{3}$$

and θ_i is a positive parameter and χ^* is the equilibrium value of $y_{i,t}$ (i.e. the equilibrium price differential between two markets). It is important to note that this value of χ^* quantifies the abstract idea of transaction cost (inclusion of shipping costs, storing costs; inland transport costs, loading cost and unobserved hidden costs originated from heterogeneous institutional arrangements for different locations); $\mu_{i,t}$ is the error term and it has a one-factor structure such as:

$$\mu_{i,t} = \gamma_i f_t + \varepsilon_{i,t} \tag{4}$$

$$(\varepsilon_{i,t})_t \sim i.i.d.(0, \sigma_i^2) \tag{5}$$

where f_t is the unobserved common factor and $\varepsilon_{i,t}$ is the individual-specific (idiosyncratic) error. Following the literature, we set the delay parameter d to unity such that Equation (5) in its first difference yields:

$$\Delta y_{i,t} = \alpha_i + \xi_i y_{i,t-1} + \sum_{h=1}^{h-1} \delta_{ijh} \Delta y_{ij,t-h} + (\alpha_i^* + \xi_i^* y_{i,t-1} + \sum_{h=1}^{h-1} \delta_{ih}^* \Delta y_{ij,t-h})^* Z(\theta_i; y_{i,t-d}) + \gamma_i f + i + \varepsilon_{i,t} \tag{6}$$

Several characteristics of Equation (6) are noteworthy:

a) When $y_{i,t-d} = c$, $Z(.) = 0$ the equation converges to the linear augmented Dickey-Fuller model.

b) When the price difference between two markets is far from its equilibrium level[4] it

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[4] Literally, the term equilibrium means at this level of price differential that the market i has no incentive to change its current exporting price after taking into consideration all of the transaction costs and potential profit.

implies the differential between $y_{i,t-d}$ (i.e. the actual coal price difference d lagged periods) and χ is too large, a new linear augmented Dickey-Fuller model with parameter $\beta_i = \xi_i + \xi_i^*$ in Equation (2) will emerge immediately because $Z(.)$will approach 1.

c) As the gap between the actual and equilibrium level of the coal price difference between the two markets is negligible, the parameter ξ_i^* is responsible for the movement of $y_{i,t}$. Or, if the gap between the actual and equilibrium level of the price difference is too large, ξ_i^* will dominate the adjustment process of the relative coal price in Equation (2).

d) As discussed in the literature, $\xi_i + \xi_i^* < 0$ is the necessary condition for global stability to hold. As long as $\xi_i + \xi_i^* < 0$ holds in the adjustment process, $\xi_i^* \geq 0$ can exist.

e) $y_{i,t}$ may follow a non-stationary process (e.g. a random walk or possibly an explosive innovation within the band of inaction of ξ^*) and it will converge to its equilibrium level when the magnitude of price divergence is outside the "band".

Once we assert that $y_{i,t}$ follows a unit root process in the middle regime of $\xi_i = 0$, the Equation (5) can be rewritten as:

$$\Delta y_{i,t} = \xi_i^* y_{i,t-1}[1 - exp(-\theta_i y_{i,t-1}^2)] + \gamma_i f_t + \varepsilon_{i,t} \tag{7}$$

We can form the null hypothesis of non-stationarity $H_0 : \theta_i = 0 \forall i$ against its alternative $H_1 : \theta_i > 0$ for $i = 1, 2, ..., N_1$ and $\theta_i = 0$ for $i = N_1 + 1, ..., N$. Due to the fact that ξ_i^* is not identified under the null hypothesis, the null hypothesis cannot be tested. Cerrato et al. (2011) use a first-order Taylor series approximation method that reparametrizes Equation (7) and the auxiliary regression yields:

$$\Delta y_{i,t} = a_i + \delta y_{i,t-1}^3 + \gamma_i f_t + \varepsilon_{i,t} \tag{8}$$

Equation (8) can be extended if errors are serially correlated becoming:

$$\Delta y_{i,t} = a_i + \delta y_{i,t-1}^3 + \sum_{h=1}^{h-1} \vartheta_{i,h} \Delta y_{i,t-h} + \gamma_i f_t + \varepsilon_{i,t} \tag{9}$$

Cerrato et al. (2011) further prove that the common factor f_t can be approximated by:

$$f_t \approx \frac{1}{\tilde{\gamma}} \Delta \tilde{y}_t - \frac{\tilde{b}}{\tilde{\gamma}} \tilde{y}_{t-1}^3 \tag{10}$$

where $\tilde{y}_t$ is the mean of $y_{i,t}$ and $\tilde{b} = \frac{1}{N} \sum_{i=1}^N b_i$. Combining Equation (9) and Equation (10), it can be written as the following non-linear cross-sectionally augmented DF (NCADF) regression:

$$\Delta \tilde{y}_{i,t} = a_i + b_i \tilde{y}_{i,t-1}^3 + c_i \Delta \tilde{y}_t + d_i \Delta \tilde{y}_{t-1}^3 + \varepsilon_{i,t} \tag{11}$$

t-statistics can be derived from $\hat{b}_i$, which are denoted by:

$$t_{iNL}(N,T) = \frac{\hat{b}_i}{s.e.(\hat{b}_i)} \tag{12}$$

where $\hat{b}_i$ is the OLS estimate of b_i, and $s.e.(\hat{b}_i)$ is its associated standard error. The t-statistic in Equation (12) can be used to construct a panel unit root test by averaging the individual test statistics:

$$t_{iNL}(N,T) = \frac{1}{N}\sum_{i=1}^{N} t_{iNL}(N,T) \tag{13}$$

This is a non-linear cross-sectionally augmented version of the IPS test (NCIPS).

4.3. Spillover Index

This study also employs the Diebold and Yilmaz (2012) (DY) framework to measure the price dynamics and the intensity of information transmission across global coal markets. The DY framework is based on a generalized vector autoregressive (VAR) model and has been actively employed in the finance literature to investigate spillover effects across various financial markets (Diebold and Yilmaz (2009); Batten et al. (2014); Yarovaya and Lau (2016)). However, to the best of our knowledge, this methodology has not yet been applied to coal data or to the analysis of coal markets.

The spillover index approach allows presentation of the empirical results in the form of spillover tables and spillover plots, visualizing the channels and the dynamics of information transmission across markets. Furthermore, the DY framework can provide a clear evidence of net-contributors and net-recipients of information in the international coal market. The DY framework can be described as follows.

Consider a covariance stationary N-variable VAR (p), $Xt = \sum_{i=1}^{p} = \Psi_i X_{t-i} + \varepsilon_t$, where Ψ_i is a paremeter matrix, and $\varepsilon \sim (0;\Sigma)$ is a vector of independently and identically distributed disturbances. The VAR model can be transformed into a moving average (MA) representation, $X_t = \sum_{i=o}^{\infty} A_i \varepsilon_{t-i}$, where A_i is ans $N \times N$ identity matrix $A_i = \Psi_1 A_{i-1} + \Psi_2 A_{i-2} + ...\Psi_p A_{i-p}$ beign an $N \times N$ identity matrix and with $A_i = 0$ for $i < 0$. The DY framework relies on the N-variable VAR variance decompositions that allows for each variable X_i to be added to the shares of its H-step-ahead error forecasting variance, associated with shocks of relevance to variable X_j (where $\forall_i \neq j$ for each observation). This provides evidence on the information spillovers from one market to another. Besides detecting the cross variance shares, the DY framework defines own variance shares as the fraction of the H-step ahead error variance in predicting X_i due to shocks in X_i. Following Diebold and Yilmaz (2012), the methodological framework employed in this paper relies on KPPS H-step-ahead forecast errors, which are invariant to the ordering of the variables in comparison to the alternative identification schemes like that based on Cholesky factorization (Diebold and Yilmaz (2009)) and can be defined for $H = [1, 2... + \infty)$, as:

$$\vartheta_{ij}^{g}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \Omega e_j)^2}{\sum_{h-0}^{H-1} (e_j' A_h \Omega A_h' e_i)} \tag{14}$$

where Ω is the variance matrix for the error vector ε; σ_{jj} is the standard deviation of the error term for the jth equation; e_i is the selection vector, with one as the ith element and zero otherwise. The sum of the elements in each row of the variance decomposition $\sum_{j=1}^{N} \vartheta_{ij}^{g}(H)$ is not equal to 1. The normalization of each entry of the variance decomposition matrix by the row sum can be defined as:

$$\tilde{\vartheta}_{ij}^{g}(H) = \frac{\vartheta_{ij}^{g}(H)}{\sum_{j=1}^{N} \vartheta_{ij}^{g}(H)} \tag{15}$$

where $\sum_{j=1}^{N} \tilde{\vartheta}_{ij}^{g}(H) = 1$ and $\sum_{i,j=1}^{N} \tilde{\vartheta}_{ij}^{g}(H) = N$.

The total volatility contributions from KPPS variance decompositions are used to calculate the Total Spillover Index (TSI):

$$TSI(H) = \frac{\sum_{i,j=1,i\neq j}^{N} \tilde{\vartheta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\vartheta}_{ij}^{g}(H)} \times 100 = \frac{\sum_{i,j=1,i\neq j}^{N} \tilde{\vartheta}_{ij}^{g}(H)}{N} \times 100 \tag{16}$$

We also estimate Directional Spillover Indices (DSI) to measure spillovers from market i to all markets j, as well as the reverse direction of transmission from all markets j to market i, using equations (4) and (5), respectively:

$$DSI_{j\leftarrow i}(H) = \frac{\sum_{i,j=1,i\neq j}^{N} \tilde{\vartheta}_{ji}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\vartheta}_{ij}^{g}(H)} \times 100 \tag{17}$$

$$DSI_{i\leftarrow j}(H) = \frac{\sum_{i,j=1,i\neq j}^{N} \tilde{\vartheta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\vartheta}_{ij}^{g}(H)} \times 100 \tag{18}$$

Finally, we explore who are the net-contributors and net-recipients of information in the international coal market, using the Net Spillover Index (NSI) calculated as the difference between total shocks transmitted from market i to all markets j and those transmitted to market i from all markets j:

$$NSI_{ij}(H) = \frac{\sum_{i,j=1,i\neq j}^{N} \tilde{\vartheta}_{ji}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\vartheta}_{ij}^{g}(H)} - \frac{\sum_{i,j=1,i\neq j}^{N} \tilde{\vartheta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\vartheta}_{ij}^{g}(H)} \times 100 \tag{19}$$

4.4. *Asymmetric Causality*

The asymmetry in causal linkages between international coal prices is assessed using the asymmetric causality test by Hatemi-J (2011) and the suggested bootstrap simulation technique for calculating critical values. The approach to transform the data into both cumulative positive and negative innovations was introduced by Granger and Yoon (2002) to test time-series for cointegration and it later has been adopted by Hatemi-J (2011). In effect, we examine whether or not a series negative, or positive, innovations shows greater causal impact on other series negative, or positive, innovations.

Assume that two integrated variables y_{1t} and y_{2t} are described by the following random walk processes:

$$y_{1t} = y_{1t-1} + \theta_{1t} = y_{1,0} + \sum_{i=1}^{t} \theta_{1i}^{+} + \sum_{i=1}^{t} \theta_{1i}^{-}, \tag{20}$$

and similarly

$$y_{2t} = y_{2t-1} + \theta_{2t} = y_{2,0} + \sum_{i=1}^{t} \theta_{2i}^{+} + \sum_{i=1}^{t} \theta_{2i}^{-}. \tag{21}$$

The cumulative sums of positive and negative shocks of each underlying variable can be defined as follows:

$$y_{1t}^{+} = \sum_{i=1}^{t} \theta_{1i}^{+}, y_{1t}^{-} = \sum_{i=1}^{t} \theta_{1i}^{-}, y_{2t}^{+} = \sum_{i=1}^{t} \theta_{2i}^{+}, y_{2t}^{-} = \sum_{i=1}^{t} \theta_{2i}^{-}, \tag{22}$$

where positive and negative shocks are defined as: $\theta_{1t}^{+} = max(\Delta\theta_{1i}, 0)$; $\theta_{2t}^{+} = max(\Delta\theta_{2i}, 0)$; $\theta_{1t}^{-} = min(\Delta\theta_{1i}, 0)$; $\theta_{2t}^{-} = min(\Delta\theta_{2i}, 0)$.

To test the causalities between these components, a vector autoregressive model of order p, VAR (p) is used:

$$y_t^{+} = v + A_1 y_{t-1}^{+} + ... + A_p y_{t-1}^{+} + u_t^{+}, \tag{23}$$

where $y_t^{+} = (y_1 t^{+}, y_2 t^{+})$ is the 2×1 vector of the variables, v is the 2×1 vector of intercepts, and u_t^{+} is a 2×1 vector of error terms (corresponding to each of the variables representing the cumulative sum of positive shocks); A_j is a 2×1 matrix of parameters for lag order $\gamma(\gamma = 1, , p)$. The information criterion proposed by Hatemi-J (2003) is used to select the optimal lag order (p):

$$HJC = \ln(|\hat{\Omega}_j|) + j(\frac{n^2 \ln T + 2n^2 \ln(\ln T)}{2T}), \tag{24}$$

where $j = 0, ..., p$; $|\hat{\Omega}_j|$ is the determinant of the estimated variance-covariance matrix of the error terms in the VAR model based on the lag order j, n is the number of equations in the VAR model and T is the number of observations.

This information criterion was proposed by Hatemi-j (2008). The simulation experiments confirmed the robustness of this criterion to ARCH effects, which is important in case of our study due to the existence of heteroskedasticity in the data. The next step of the analysis is to test the Null Hypothesis that the kth element of y_t^+ does not Granger-cause the ωth element of y_t^+ using the Wald test methodology. Furthermore, Hatemi-J (2012) employs a bootstrap algorithm with leverage correction to calculate the critical values for the asymmetric causality test in order to remedy the heteroskedasticity problem. The details of the Wald test methodology and the bootstrap procedure are discussed in depth by Hacker and Hatemi-J (2012).

5. Empirical Results

5.1. Cointegration and Long Term Linkages

As mentioned earlier, the primary purpose of this paper is to identify spillovers and causality effects between the international coal markets rather than examining their cointegration properties, which was thoroughly analyzed in (Papiez and Smiech, 2015). However, since our data covers a longer time period and, also, since we include China in our analysis, we begin by providing updated evidence on the cointegration of international coal prices and report the results in Table 2. We also examine the drivers of the system of the coal prices to provide information on the long term spillovers.

We first test for the cointegration rank of the system. Similar to Papiez and Smiech (2015) we rely on the full information maximum likelihood method of (Johansen et al., 2000). Since the econometric details of this approach are commonly known, we do not discuss them in this study. However, it should be mentioned that in Johansens method, an important issue prior to conducting the rank tests, is to establish how to deal with any trend in the system, i.e. specifically whether the trend should enter only in the cointegration relation (Johansens Case 2) or whether the trend should be orthogonal to the relation (Johansens Case 3). There is no clear trend in the coal price series, which suggests adopting Case 2. However, we also test this restriction by means of a likelihood ratio test and the null hypothesis of restricting the trend cannot be rejected.

The second issue is related to the fact that there is a structural break in the system, as we detect in this study, during the Global Financial Crisis. Structural breaks could significantly impact the conclusions of the Johansen (1991) cointegration analysis. In fact, Papiez and Smiech (2015) state this as one of their primary reasons for conducting rolling tests, since the full sample analysis could be unreliable. While there is definitely merit in such approach, it should also be mentioned that Johansen et al. (2000) and Lütkepohl et al. (2004) discuss how the method can be adjusted in the presence of a structural break.

Therefore, in this paper, we follow the (Johansen et al., 2000) method of analysis, to estimate the p-values for the likelihood ratio (trace) tests to test for cointegration by using the structural break date identified in the paper on September 14, 2007.

Panel A in Table 2 reveals noteworthy findings. First, we detect five cointegration relations in the system. This is consistent with our intuition that in the long term international coal prices will not drift apart arbitrarily from each other. The number of the relations is also largely consistent with the evidence presented in Papiez and Smiech (2015), although the analyses is not directly comparable for the reasons mentioned above. However, also note that we do not find seven cointegration relations, which would indicate perfect convergence between the international coal prices and, hence, the presence of the law of one price.

In Panel B of Table 2, we report loading coefficients for the coal markets for each of the cointegration relations. Loading, or speed of adjustment, shows the statistical significance of the response of each of the coal markets when the system moves away from equilibria. The purpose of this analysis is to identify which market adjusts least to any disequilibria, since this one would be the market that drives the long term trend. The loading coefficients for Australia are never significant, which indicates again that Australia does not respond to disequilibria. In turn, all of the other markets show significant adjustment to changes in the cointegration vectors. In other words, they correct for the errors in the system.

In Panel C of Table 2, the focus is on the forecast error variance decompositions (FEVDs) of the system of equations. The FEVDs provide information on how much of the variables movements are explained by the past movements of another variable. Since the purpose in this section is to provide evidence on long term relations, we calculate the FEVDs for 26 and 52 week horizons. We argue that Australia appears to be driving the long term trend in the system.

If that contention is correct, we should find that the Australian coal price has noticeable explanatory power for the other prices at these horizons. The results are highly consistent with this argument. Specifically, after 52 weeks, Australia's own information explains almost 90 percent of its own movements. In other words, the influence of the other markets on the price changes in Australia is very limited, as we would expect in the case of the leader of the system. On the other hand, Australia has significant explanatory power for all of the other markets in the system. This is again consistent with our contention. For example, after 52 weeks, 73 percent and 70 percent of price changes in COBA and SAMA, respectively, are explained by Australia.

5.2. Market Integration: Nonlinear Panel Unit Root Test

Having found a break in the market on September 14, 2007 we now examine the degree of market integration pre and post this break. The findings of the nonlinear panel unit root test indicate that most markets were converging to the mean price index before 2007 with the exception of two Russian markets and the Australian market (see the left panel of Table 5). However, after the break only the American market and the European market diverge from the mean (see the left panel of Table 3).

5.3. Return and Volatility Spillovers Across Market

The empirical results of the DY spillover tests are reported in Table 6 for the coal prices and Table 7 for volatility. The findings indicate that the Total Spillover Index for the market is 73 %. This implies a well-integrated international market with 73% of the variation in the market price originating within it. Table 6 also displays values of the net-spillover indices for each individual market, and indicates the net-contributors and net-recipients of coal price spillovers.

The contribution of the Australian market to other markets is 210.85 %, which is the highest in the sample[5], whereas Australia contributes 39.4% of spillover indexes to South Africa. In contrast, Colombia only transmits 5% to the other markets, while China receives the most price spillovers from the other markets (i.e. 84.13 %), which makes it the largest net-recipient of price spillover in the global market. In summary, Australia and Mozambique are the net-contributors of the coal price spillover index, while the net-recipients are China, Colombia, Europe, Baltic, Russian Vostochny, and South Africa.

We define price volatility as the absolute return[6]: $V_t = |ln(P_t) - ln(P_{t-1})|$, where P_t is the weekly closing price of the coal price on day t. Table 7 shows the Total Volatility Spillover Index for the coal price (i.e., 51.5%), which is appropriately 21.5% lower than the price spillover. However, we still see that in general over half the volatility in the world coal market is internally generated. In particular, the contribution of China, in terms of volatility spillovers, turns out to be the highest (i.e. 79.14%), while it contributes 17.05% to Europe. Colombia transmits only 26.24% to other countries, while Europe receives 62.38%

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[5] Australia exports 90% of its coal output. Australia is the world's second biggest net exporter of coal in 2017, and the total amount of coal exports was 379Mt in 2017.

[6] This same calculation is used by recent studies including Forsberg and Ghysels (2007), Antonakakis and Kizys (2015), and Wang et al. (2016).

of volatility spillovers from other countries. Overall, Australia, Europe, Baltic, Mozambique and China are the net-contributors of price volatility, while the net-recipients are Colombia, Vostochny and South Africa.

Fig 1 shows the dynamics of the coal price spillovers in the international market using a 60 weeks rolling window. Fig 1 indicates time-varying dynamics for the total price spillovers indices. We note a clear, but gradually increasing, trend of international coal market total spillovers over the period April 2005 to September 2007. This is most likely due to a relatively competitive steam coal market from 2005 to 2008 and there is evidence that steam coal prices were driven by fundamentally marginal cost (i.e. mining cost escalation and freight rates) based from 2005 to 2008 ((Trüby et al., 2010)). However, the degree of connectedness, starting from September 2008, decreases as the global financial crisis worsened. Figure 2 presents a similar analysis for volatility. It depicts a solid increase in the within system volatility spillover that mirrors the decline in the price spillover with the system settling at a more or less steady state after 2007.

5.4. Time-Frequency Decomposition of International Coal Market Prices Connectedness

We now further investigate the degree of time variation in the system using the spectral representation of GFEVD as derived in Barunik and Krehlik (2015). It is possible to define an aggregate measure of the frequency band d specified as[7]:

$$\widetilde{C}^d = C^d \cdot SW(d) \tag{25}$$

where the spectral weight $SW(d) = \frac{\sum_{i,j=1}^{k} (\widetilde{\theta}_d)_{i,j}}{\sum_{i,j} (\theta)_{i,j}} = \frac{\sum_{i,j=1}^{k} (\widetilde{\theta}_d)_{i,j}}{k}$ is the contribution of frequency band d to the whole VAR system, and C^d is the total connectedness measure on the connectedness tables $(\widetilde{\theta}_d)$ corresponding to an arbitrary frequency of band d. It is important to note that the total connectedness measures (C) as defined in (Diebold and Yilmaz, 2012) can be calculated as $C = \sum_d \widetilde{C}^d$. The time-frequency dynamics of connectedness can be obtained by using the spectral representations of variance with moving window of 200 trading weeks. We use two lags to capture the dynamics in the window. The time-frequency decomposition of price connectedness is presented in Table 8. With weekly data we then have 1-5 weeks, 5-20 weeks, 20-60 weeks and 60-200 weeks as the time spectrum[8]. We set

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[7] For detailed derivation of the GFEVD and explanation of the proposed time-frequency dynamics of connectedness measures, please refer to page 29 Barunik and Krehlik (2015).

[8] In the R script we set bounds $< -c(pi + 0.0001, pi/c(4, 12, 48), 0)$ such that we have weekly, monthly, quarterly and yearly cycles. Literally we are investigating time domain on 1-5 weeks, 5-20 weeks, 20-60 weeks, and 60-200 weeks.

the H steps forecast horizon to be 100 as an approximation of the frequencies (especially for low frequencies around zero this choice is appropriate). As we take a Fourier transform of the impulse response functions, we therefore need larger forecast horizons to obtain low frequencies.

In a similar analysis, Greenwood-Nimmo et al. (2015) notes that with increasing horizon, directional connectedness intensies, and rapidly converges to a long-run value. While this is attributed to gradual transmission of shocks, we add that this behaviour is also perhaps due to a long frequency response of the shocks. Increasing the horizon will then only better approximate the permanent effects of shocks. Moreover, the nature of the shocks will not allow isolation of the connectedness at business cycle frequencies, as discussed earlier. Here, using frequency responses of shocks and our spectral representation of measures will be useful. Table 8 shows the connectedness at different cycle frequencies and it reveals how the system was connected in these cycles.

We find that the largest connectedness comes from frequencies higher than yearly cycles (i.e. 60-200 weeks) with a value of 80.1, while the weekly, monthly and quarterly cycles are connected with values of 0.3, 0.7 and 2.6, respectively. Previous studies use aggregate effects to measure market connectedness by applying methods of causality testing, systemic risk, co-movement and spillovers index. but they emphasize the empirical importance of frequency sources of connectedness, arguing that shocks to volatility will impact differently on future uncertainty [9].

More generally, Table 8 reinforces the importance of Australia at all frequencies, as the main source of price contribution, which is followed by South Africa albeit at a lower level. Columbia, at the shorter frequency, is also an important net-contributor. Indeed, at the shorter cycles, it is Columbia that tends to be the largest gross (but not net) contributor. This is consistent with a segmented market both in terms of geography and time. Furthermore, the Australian market receives the highest spillover index (i.e. at 60-200 weeks frequency) from South Africa and Russia Vostochny has the lowest connectedness with the Baltic. The decomposition shows that the largest portion of connections is created from lower frequencies of 60 weeks up to 200 weeks and higher frequencies up to one month play an insignificant role in the degree of connectedness. Our results also provide important insights into the time dynamics of the frequency connections since there is a clear pattern of lower frequency bands

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[9] Changes in mining cost escalation and freight rates may trigger fundamental changes in investors expectations, and this shock will impact the market in the longer term. These long-term expectations may transit to surrounding coal markets in the portfolio differently than shocks that have a short-term impact.

dominating all others, whereas connectedness has been driven mostly by yearly information.

5.5. Asymmetry in Price Spillovers

Finally, we analyse how positive and negative innovations on one market affect positive and negative innovations in another market. Table 9 reports the results of the application of the asymmetric causality test by Hatemi-J (2011) to coal prices. The results are organized by presenting them for each market as a contributor of information.

Table 9 shows that for majority of market pairs an asymmetry in spillover effect is not evident, i.e. the transmission of both negative and positive innovations is equally pronounced. It is clearly visible, for example, for China, Europe and the South Africa markets (Panel B, C and G). However, there are a few notable exceptions. A decline in coal prices in the Colombian market causes a decline in prices in the Australian, Vostochny, Baltic, South Africa and Mozambique markets, while an increase in prices in the same Colombia market causes only an increase in the Baltic market. This indicates that the transmission of negative shocks from this market is stronger than the transmission of positive shocks. Similar patterns of transmission are evident for the Australia-Baltic and Australia-Mozambique market combinations in Panel A, Baltic-Colombia, Baltic-China and Baltic-Mozambique pairs in Panel E and also Vostochny-Europe, Vostochny-Europe and Vostochny-Mozambique as shown in Panel F. The results for Europe-China, Vostochny-China and Mozambique-China illustrate the transmission of positive shocks only, which shows that the market of China is more susceptible to positive spillover effects from other markets. This is also evident for the South Africa-Mozambique and Mozambique-Europe market pairs (Panels G and E).

6. Trading Strategies

In this section, we provide indication regarding how our results reported so far can be used for the design of hypothetical trading strategies relying on the findings presented previously about the markets which have been identified as net-contributors and net-recipients.

The information about the coal prices divided into two groups of net-recipients and net-contributors can be exploited in a relatively simple 'long-short strategy' based on the assumption that the net-recipients are the markets which receive signals and the net-contributors are the markets which send signals. It implies that when a trader opens a long position in the net-recipients prices, it can be hedged by opening a short position in the net-contributors prices.

We simulate three different strategies for comparison and they are constructed as follows. Strategy 1 relies on all markets in our sample, where long positions are opened in the coal prices of all net-recipients (China, Europe, Colombia, Russia Baltic, Russia Vostochny and Mozambique) and short positions are opened in all markets of net-contributors (Australia and South Africa). In Strategy 1 all markets are equally weighted, i.e. they have weights 25% in case of net-recipients and 50% in case of net contributions. Strategy 2 is also based on all markets in our sample, and long positions are opened in the coal prices of all net-recipients while short positions are opened in all markets of net-contributors, however the weights are now not equal but they are allocated according to the value of their contribution within each group (as reported earlier in Table 6). Strategy 3 extracts only the markets, which are the strongest influencer (Australia) and the most sensitive recipient (China), so a long position is opened in the coal price in China and it is hedged by a short position in the coal price in Australia.

The calculations cover our entire sample period and the data frequency is weekly. We compute the net result of the long and short positions each week and we report it for all three strategies in Table 10.

As Table 10 illustrates, all three strategies deliver positive net returns. The sum of weekly differences in returns between long and short positions in Strategy 1 with equal weights is +16.69% and it is slightly higher +19.26% in case of Strategy 2 with weights allocated according to the markets actual contributions. However, the best result by far is achieved by Strategy 3 with only Australia and China coal prices, for which the sum of weekly differences in returns between long and short positions is +52.43%.

Similarly, the average weekly difference in returns between long and short positions is positive in all three cases and it has the highest value of +0.0719% for Strategy 3.

The results adjusted for risk confirm this pattern. The ratio of the sum of the weekly differences in returns between long and short positions to the weekly standard deviation of the long-short strategy returns is: 5.70, 6.59, 13.28 for Strategy 1, Strategy 2 and Strategy 3, respectively.

The positive results from the strategies presented in Table 10 may reflect transportation and storage costs equivalent to the costs of arbitrage, although they are not pure arbitrage strategies and, given the nature of the coal business trade, the assessment of such costs is difficult because they vary according to markets, there are such issues as sovereign risk which affects funding costs etc. and, finally, due to limitations in access to such data. The decomposition of arbitrage costs is also outside the scope of the existing work in this paper.

7. Discussion

In this section, we provide a discussion of our results along with their broader economic interpretation and we indicate some possible implications of our findings for international steam coal market participants, such as producers, traders and financial investors.

The empirical results, which we reported so far, clearly point towards the conclusion that the steam coal trading centre in Australia is the most influential market around the globe with by far with the highest 'Contribution to Others' value and with the lowest value for 'Contribution from Others' in terms of price spillovers, as it is demonstrated in Table 6. Hence, we can interpret this finding that Australia is the most dominant coal trading centre and at the same time it is also least sensitive to other markets. In addition, Table 7 shows a confirmation of the leading role of Australia also in terms of volatility, where it has the lowest value in the 'Contribution from Others', so it is least susceptible to the volatility shocks from other coal markets.

Our general finding about dominant role of Australia is consistent with the results reported previously by Papiez and Smiech (2015), who provided evidence that Australian market (i.e. the "Newcastle port" in their study) gained importance over time as a 'price setter' Papiez and Smiech (2015) attribute the pattern of their results to the fact that the 'price setters' have well developed futures markets, even if they are not the largest international coal producers or exporters).

The international steam coal market has a specific structure in terms of supply (naturally segmented markets due to physical and geographical barriers based on freight and quality etc.) and demand (major energy source, especially for emerging economies, but nowadays subject to competition from alternate energy sources due to concerns over pollution etc.). The dominance of Australia forms part of the broader picture where there is existence of two regional and segmented markets, i.e. Atlantic (Americas to Europe) and Pacific (Australia and Indonesian exports to Asia), which based on our results and the findings reported in other earlier studies, such as Papiez and Smiech (2015), can now be restated as a segmented market led by Australian coal prices [10].

The dominant role of Australia can be explained by a number of different factors related to: (1) quality of coal, (2) technical constraints, (3) geographical circumstances and (4) nature of the coal extraction, production and transportation processes. We discuss them in turn below.

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[10] For statistical information please see http://www.worldcoal.org/coal/coal-market-pricing

The simple price correlations between Australian, Colombian and South African monthly coal data (about 70% between each) are due to their equivalence in terms of quality (energy, ash and metal pollutants). However, while they may be equivalent, the bulky nature of the material ensures that transport costs effectively underpin market segmentation, but bigger ships may erode regional cost advantages over time. Thus, in the medium term in a world with lower and better available alternate energy sources, (primarily) gas relative price differences between the grades of coals should become more apparent and, as our results suggest, favour Australia.

Another important issue are the technical constraints on grade of thermal coal used in power stations (for example, Japan values higher grade coal shipped from Australia). The role of Australia as the global leader is consistent with a ”quality” benchmark forming the benchmark pricing curve (spot to forward).

Moreover, the competition with alternate energy sources, especially gas causing the price to fall, favours purchasing the better quality thermal coals (as cheaper and less polluting energy source). There is also the likely retirement of less efficient and polluting plants due to stricter emissions standards that again favour better quality coal.

While China is a major producer of coal, the production is concentrated in the north-eastern part of the country, while the factories are on the coast (dito India). Thus, the geographical isolation of the Chinese local supply and improvements in Australia extraction and lowering of production costs favour the importing of higher grade (and likely cheaper) Australian coal to the Chinese coastal power plants. Although some of the mining literature argues that the quality of Australian coal is questionable (high energy but high ash), some of the ash is typically washed prior to export. The new rules in China will support the import of better quality coal.[11]

Last but not least, competition between markets and the foreign exchange rates dynamics are also an important part of the broader picture. Coal is priced in USD, but key cost extraction components (labour and maintenance expenses) may assist production cost reduction and maintain mine profits despite a fall in USD prices. In the case of Australia, the

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[11] ’Under new Chinese regulations, the use of coal with ash content higher than 16% and sulfur content above 1% will be restricted in the main population centres of the country from 1 January, 2015.There will be a ban on mining, sale, transportation and imports of coal with ash and sulfur content exceeding 40% and 3% respectively. For coal that will be transported for more than 600 km from production site or receiving port, the ash content limit will be 20%’. https://www.theguardian.com/world/2014/sep/17/chinas-ban-on-dirty-coal-could-cost-australian-mining-almost-15bn

devaluation of the AUD (some 30% against the USD in the past few years) partly offsets the impact of the fall in coal prices. Thus, the mines may remain profitable due to reduction in the USD equivalent cost of some key expenses. The fall in the price of oil in recent years would also assist reduction in costs.

8. Conclusion

We examined the interconnectedness of the global steam coal market. Using a variety of recent econometric techniques, we uncovered a number of important relationships that have not previously been identified in the exisitng literature. In contrast to Papiez and Smiech (2015), who found that the ARA ports, the Richards Bay port and the Puerto Bolivar port are prices-setters, we show that Australia, and to a lesser extent Mozambique, are the dominant source of price spillovers on the global coal market. China remains a price taker, which is surprising given its large imports. It is, however, the single largest source of volatility to the global coal market. The global coal market appears to have a considerable degree of integration with 70% or more of price variation being generated within the market and more than 50% of the volatility. This finding about integration is similar to the result reported in Li et al. (2010b). These relationships are, for positive and negative innovations, generally symmetrical. There is no evidence of enhanced market reaction to either positive or negative news.

Our study extends the results of Papiez and Smiech (2015) using a different set of techniques and different data. Common to both are the results that demonstrate a significant degree of interconnectedness and integration in the markets, a break or change in the degree of this integration in and around the commencement of the GFC, and the finding that Australia sets the prices. Unlike Papiez and Smiech (2015), we also include China, the world's largest coal market, and we report the results indicating its relative position. We also show that the coal market is symmetrical in its reactions.

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Table 1: Summary statistics: International coal price index

	Australia	Colombia	Europe	Russia Baltic	Russia Vostochny	Sth. Africa	Mozambique	China
Mean	69.189	66.045	64.818	69.783	72.163	64.538	67.312	81.056
Median	65.600	62.000	60.000	65.000	69.000	58.590	62.300	84.950
Maximum	192.500	174.500	174.500	194.000	175.000	172.000	176.800	168.000
Minimum	21.760	25.800	22.400	22.170	23.000	19.900	20.640	24.000
Std. Dev.	33.692	26.915	28.027	31.247	33.841	30.741	30.873	41.213
Skewness	0.640	1.139	1.028	1.089	0.491	0.634	0.646	0.195
Kurtosis	3.045	4.619	4.323	5.068	2.731	2.968	3.071	1.794
Jarque-Bera	49.824	237.195	181.438	273.950	31.535	48.835	50.875	48.818
Probability	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Observations	729	729	729	729	729	729	729	729

Table 2: Cointgrating and Longterm Relations

Panel A: Cointegration Tests

r0	LR	p-value
0.00	370.93	0.00
1.00	272.78	0.00
2.00	194.07	0.00
3.00	132.43	0.00
4.00	86.27	0.00
5.00	49.41	0.02
6.00	22.56	0.21
7.00	2.44	0.95

Panel B: Loading Coefficients

	dAustralia	dChina	dColombia	dSouthAFrica	dBaltics	dVostochny	dEurope	dMozambique
ec1(t-1)	0.00	0.05	0.05	0.06	0.00	0.07	0.05	0.05
	{0.61}	{0.00}	{0.00}	{0.00}	{0.86}	{0.00}	{0.00}	{0.00}
ec2(t-1)	0.01	-0.04	-0.03	-0.04	-0.02	0.00	0.03	0.01
	{0.27}	{0.00}	{0.01}	{0.00}	{0.07}	{0.76}	{0.02}	{0.40}
ec3(t-1)	0.01	-0.03	-0.14	-0.03	-0.04	-0.06	-0.07	-0.01
	{0.48}	{0.14}	{0.00}	{0.30}	{0.09}	{0.00}	{0.00}	{0.66}
ec4(t-1)	0.00	-0.02	0.03	-0.03	0.01	0.00	0.03	-0.02
	{0.97}	{0.04}	{0.02}	{0.04}	{0.28}	{0.99}	{0.02}	{0.18}
ec5(t-1)	0.00	0.01	0.04	0.00	-0.03	0.06	0.06	0.06
	{0.56}	{0.39}	{0.03}	{0.96}	{0.08}	{0.00}	{0.00}	{0.00}

Panel C: Forecast Error Variance Explained by Australia

	Australia	China	Colombia	SouthAFrica	Baltics	Vostochny	Europe	Mozambique
26-weeks	0.93	0.50	0.61	0.64	0.42	0.68	0.66	0.65
52- weeks	0.89	0.55	0.67	0.73	0.48	0.69	0.70	0.67

Note- This table provides the results of the cointegration tests
in Panel A. The system is estimated by 3 lags, determined by the Hannah- Quinn criteria
in Panel B, statistical significance of the speed of adjustment coefficients are provided.
In Panel C, the forecast error variance explained by Australia for each variable is reported.

Table 3: Stationarity test with structural break

Panel A: Univariate unit root test/stationarity test			Innovational Outlier Test	
Variables	P-value (ADF)	P-value (PP)	P-value (Model A)	Break Date
Aus	0.563	0.602	0.641	21/09/2007
Colombia	0.209	0.366	0.467	14/09/2007
Europe	0.237	0.400	0.495	14/09/2007
Baltic	0.083	0.349	0.152	11/07/2008
Vostochny	0.708	0.678	0.965	12/10/2007
Sth. Africa	0.207	0.447	0.302	14/09/2007
Mozambique	0.805	0.473	0.922	14/09/2007
China	0.478	0.653	0.513	24/09/2010

Panel B: Panel unit root test

Test		Coal Price Index (p-value)
Im, Pesaran, and Shin (2003)		0.1823
Hadri (2000)	Homogenous variance	0.000
	Heterogeneous variance	0.000

Note: For PP test, the selected truncation for the Bartlett Kernel are based on the suggestion by Newey and West (1994).

The optimum lag order is selected based on the BIC criterion.The Innovational outlier test followed Perron (1989).

It assumes that the break occurs gradually, with the breaks following the same dynamic path as the innovations.

Results for univariate unit root test with structural break is based on Vogelsang and Perron (1998) asymptotic one-sided p-values.

Table 4: Unit root test with 2 breaks and GARCH

Panel A: Univariate unit root test with 2 breaks			
Country/Market	M1	M2	
Australia	-4.742***	-4.385***	
China	1.036	-0.6506	
Europe	-0.1687	-0.8325	
Colombia	-0.3474	-1.031	
Baltic	-0.2089	-1.219	
Vostochny	-1.171	-2.456	
Sth. Africa	-0.4733	-1.935	
Mozambique	0.3481	-2.142	
Panel B: Unit root test with 2 breaks and GARCH effect			
Australia			-5.41***
China			-10.77***
Europe			-3.45**
Colombia			-2.98**
Baltic			-5.3***
Vostochny			-6.48***
Sth. Africa			-2.91**
Mozambique			-2.97**
Hadri (2000)	Homogenous variance		0.000
	Heterogeneous variance		0.000

Note: For the M1 model: Critical values at the 1% and 5% levels are - 4.672 and - 4.081, respectively. Critical values are extracted from table 3 of Narayan and Popp (2010).

For the M2 model critical values at the 1% and 5% levels are -5.287, - 4.692, respectively. Critical values are extracted from table 3 of Narayan and Popp (2010).

For the unit root test with breaks and GARCH effect, we extract appropriate CVs from Liu and Narayan (2010) , which are -3.807 and -2.869 at the 1% and 5% as the break dates fall within the range of 0.20.8 respectively.

Table 5: Nonlinear panel unit root test results (NCIPS)

States	Before		After	
Aus	-2.793		-8.4466	***
Colombia	-2.828	*	-1.7986	
Europe	-5.064	***	-1.6284	
Baltic	-2.157		-8.5946	***
Vostochny	-2.255		-4.0584	***
Sth. Africa	-3.559	***	-7.5253	***
Mozambique	-3.446	**	-6.9299	***
China	-6.746	***	-4.8645	***
Panel Stat.	-3.606	***	-5.481	***
	Critical values of Panel		Critical values of Panel	
	NCADF Distribution (N = 8, T = 349):		NCADF Distribution (N = 8, T = 381):	
	1%	-3.73	1%	-3.73
	5%	-3.12	5%	-3.12
	10%	-2.82	10%	-2.82
	Critical values of Panel		Critical values of Panel	
	NCADF Distribution (N = 8, T = 349):		NCADF Distribution (N = 8, T = 381):	
	1%	-2.50	1%	-2.50
	5%	-2.33	5%	-2.33
	10%	-2.25	10%	-2.25

Note: Critical values are from Table 13. and Table 14. of Cerrato et al., (2011).

***, **, and * denote 1%, 5%, and 10% critical values respectively.

Table 6: Price spillovers across international coal markets

	Aus	Colombia	Europe	Baltic	Vostochny	Sth. Africa	Mozambique	China	From Others*	Net	Conclusion
Australia	44.30	7.12	3.74	3.06	6.29	25.16	8.81	1.51	55.70	119.94	net-contributor
Columbia	21.96	18.73	10.87	5.30	5.19	25.68	11.76	0.52	81.27	-16.03	net-recipient
Europe	19.50	17.06	18.58	4.56	5.26	22.87	11.74	0.42	81.42	-43.26	net-recipient
Baltic	22.22	11.78	7.23	18.14	4.48	25.17	10.75	0.24	81.86	-52.27	net-recipient
Vostochny	33.44	4.74	2.31	5.88	21.40	20.81	7.71	3.70	78.60	-37.32	net-recipient
Sth. Africa	29.48	9.28	5.50	4.07	4.70	35.50	10.55	0.92	64.50	99.06	net-contributor
Mozambique	26.17	10.72	6.71	5.54	4.85	29.20	15.89	0.91	84.11	-14.29	net-recipient
China	22.87	4.54	1.79	1.18	10.51	14.67	8.50	35.94	64.06	-55.83	net-recipient
Contribution to others	175.64	65.24	38.15	29.59	41.28	163.56	69.82	8.23	591.52		
Contribution including own	219.94	83.97	56.74	47.73	62.68	199.06	85.71	44.17	73.9%		

Note: *From Others - directional indices measure spillovers from all $markets_j$ to $market_i$;

**Contrib to others - directional indices measure spillovers from all $markets_j$ to $market_i$;;

***Contrib including own - directional indices measure spillovers from $market_i$ to all $markets_j$,including from own innovations to $market_i$;

Other columns contain net pairwise (i,j)-th spillover indices.

Table 7: Volatility spillovers across international coal markets

	Aus	Colombia	Europe	Baltic	Vostochny	Sth. Africa	Mozambique	China	From Others*	Net	Conclusion
Australia	50.1	3.51	0.02	6.57	7.07	24.61	6.34	1.85	50	87.9	net-contributor
Columbia	18.89	21.73	0.54	10.76	4.57	33.14	9.76	0.6	78.3	-43	net-recipient
Europe	6.98	8.08	62.37	5.21	3.01	10.05	4.21	0.09	37.6	-35.9	net-recipient
Baltic	15.37	6.92	0.17	34.9	5.2	27.79	9	0.65	65.1	-9.4	net-recipient
Vostochny	29.53	2.99	0.4	10.05	28.72	18.49	5.72	4.2	71.3	-32.4	net-recipient
Sth. Africa	26.86	4.47	0.02	8.11	3.93	48.38	7.13	1.12	51.6	112.8	net-contributor
Mozambique	21.9	6.72	0.09	11.09	4.12	35.73	18.84	1.49	81.2	-33.6	net-recipient
China	18.32	2.56	0.48	3.93	11.04	14.56	5.48	43.62	56.4	-46.5	net-recipient
Contribution to others	137.9	35.3	1.7	55.7	38.9	164.4	47.6	9.9	491.4		
Contribution including own	187.9	57	64.1	90.6	67.7	212.8	66.5	53.5	61.40%		

Note: *From Others - directional indices measure spillovers from all $markets_j$ to $market_i$;

**Contrib to others - directional indices measure spillovers from all $markets_j$ to $market_i$;;

***Contrib including own - directional indices measure spillovers from $market_i$ to all $markets_j$,including from own innovations to $market_i$;

Other columns contain net pairwise (i,j)-th spillover indices.

Table 8: Total connectedness of coal market at different time frequencies

	Aus	Colombia	Europe	Russia Baltic	Vostochny	Sth. Africa	Mozambique	China	From Others*	Net	Conclusion
Weekly cycle											
Aus	0.082	0.026	0.022	0.000	0.006	0.055	0.031	0.004	0.145	0.221	net-contributor
Colombia	0.044	0.244	0.155	0.016	0.018	0.069	0.084	0.010	0.397	0.015	net-contributor
Europe	0.040	0.176	0.214	0.023	0.025	0.062	0.101	0.010	0.437	-0.061	net-recipient
Russia Baltic	0.078	0.015	0.015	0.416	0.021	0.042	0.025	0.002	0.199	-0.082	net-recipient
Vostochny	0.082	0.024	0.022	0.017	0.244	0.029	0.022	0.050	0.246	-0.096	net-recipient
Sth. Africa	0.030	0.050	0.042	0.007	0.002	0.198	0.050	0.002	0.183	0.188	net-contributor
Mozambique	0.050	0.111	0.115	0.046	0.034	0.081	0.233	0.005	0.443	-0.127	net-recipient
China	0.042	0.010	0.005	0.006	0.044	0.032	0.003	0.456	0.143	-0.059	net-recipient
Contribution to others**	0.366	0.412	0.376	0.116	0.150	0.371	0.317	0.084	2.192		
Contribution inc own***	0.448	0.656	0.590	0.532	0.394	0.570	0.550	0.540	0.274		
Monthly cycle											
Aus	0.3877	0.1239	0.0991	0.0037	0.0266	0.2988	0.1300	0.0204	0.7025	0.1399	net-contributor
Colombia	0.0777	0.5485	0.3378	0.0048	0.0153	0.2216	0.1634	0.0253	0.8459	0.2192	net-contributor
Europe	0.0839	0.3767	0.4204	0.0100	0.0210	0.2391	0.1692	0.0232	0.9231	-0.0167	net-recipient
Russia Baltic	0.1541	0.0734	0.0636	0.5425	0.0150	0.1731	0.0495	0.0087	0.5374	-0.4352	net-recipient
Vostochny	0.1500	0.0541	0.0401	0.0198	0.4197	0.0984	0.0450	0.0875	0.4950	-0.3226	net-recipient
Sth. Africa	0.1279	0.1777	0.1420	0.0147	0.0065	0.5360	0.1377	0.0079	0.6144	0.8466	net-contributor
Mozambique	0.1377	0.2324	0.2047	0.0264	0.0309	0.3729	0.3677	0.0100	1.0150	-0.2883	net-recipient
China	0.1110	0.0269	0.0190	0.0229	0.0570	0.0572	0.0318	0.8263	0.3258	-0.1428	net-recipient
Contribution to others**	0.8424	1.0651	0.9064	0.1021	0.1723	1.4611	0.7266	0.1831	5.4591		
Contribution inc own***	1.2301	1.6136	1.3268	0.6446	0.5920	1.9970	1.0943	1.0093	0.6824		
Quarterly cycle											
Aus	1.425	0.246	0.200	0.039	0.105	0.827	0.301	0.046	1.765	4.329	net-contributor
Colombia	0.745	1.414	0.918	0.086	0.091	0.861	0.526	0.072	3.299	-0.561	net-recipient
Europe	0.764	0.896	0.957	0.105	0.064	0.957	0.463	0.066	3.314	-0.858	net-recipient
Russia Baltic	0.951	0.537	0.496	0.634	0.024	0.985	0.337	0.081	3.411	-2.821	net-recipient
Vostochny	1.028	0.083	0.059	0.154	0.763	0.604	0.163	0.097	2.188	-1.677	net-recipient
Sth. Africa	0.879	0.357	0.302	0.086	0.041	1.307	0.413	0.007	2.085	3.757	net-contributor
Mozambique	0.883	0.494	0.379	0.063	0.042	1.173	0.699	0.012	3.046	-0.621	net-recipient
China	0.846	0.125	0.103	0.057	0.143	0.435	0.221	1.534	1.930	-1.548	net-recipient
Contribution to others**	6.094	2.738	2.456	0.590	0.511	5.842	2.424	0.382	21.038		
Contribution including own***	7.519	4.153	3.413	1.225	1.273	7.150	3.124	1.916	2.630		
Yearly cycle											
Aus	58.411	1.019	3.103	1.791	3.084	22.827	4.436	0.821	37.082	326.330	net-contributor
Colombia	47.795	4.345	6.308	3.021	3.084	23.347	5.227	0.122	88.906	-76.827	net-recipient
Europe	48.893	3.186	6.334	3.137	2.834	24.132	5.098	0.122	87.401	-58.950	net-recipient
Russia Baltic	49.232	2.810	5.489	5.035	2.664	23.980	4.782	0.269	89.225	-72.439	net-recipient
Vostochny	56.477	0.750	2.783	2.925	5.031	22.781	4.285	0.611	90.613	-70.117	net-recipient
Sth. Africa	53.535	1.601	3.883	2.271	2.599	25.872	5.015	0.298	69.203	93.958	net-contributor
Mozambique	52.189	1.929	4.102	2.403	2.703	24.706	5.814	0.349	88.382	-54.743	net-recipient
China	55.291	0.783	2.782	1.237	3.528	21.387	4.797	4.980	89.805	-87.212	net-recipient

Table 8: Total connectedness of coal market at different time frequencies

	Aus	Colombia	Europe	Russia Baltic	Vostochny	Sth. Africa	Mozambique	China	From Others*	Net	Conclusion
Contribution to others**	363.413	12.079	28.450	16.786	20.496	163.161	33.639	2.592	640.617		
Contribution inc own***:	421.823	16.424	34.785	21.822	25.527	189.033	39.453	7.573	80.077		

Note: *From Others - directional spillover indices measure spillovers from all markets j to market i;
**Contribution to others - directional spillover indices measure spillovers from market i to all markets j;
***Contribution including own - directional spillover indices measure spillovers from market i to all markets j,including contribution from own innovations to market i;
Other columns contain net pairwise (i,j)-th spillovers indices.

Table 9: Asymmetric Causality Tests for Coal Prices

Null Hypothesis	Test value	Bootstrap CV at 1%	Bootstrap CV at 5%	Bootstrap CV at 10%	Conclusion
Panel A: Australia as contributor					
Aus+≠>China+	6.776*	16.073	8.906	5.771	Aus+=>China+
Aus-≠>China-	16.975**	17.138	8.498	5.924	Aus-=>China-
Aus + ≠> Europe+	3.003	16.012	8.129	6.501	Aus + ≠> Europe+
Aus - ≠> Europe-	1.502	15.345	7.637	5.727	Aus - ≠> Europe-
Aus+ ≠> Colombia+	1.070	22.984	6.224	3.907	Aus+ ≠> Colombia+
Aus- ≠> Colombia-	0.673	14.202	8.014	6.509	Aus- ≠> Colombia-
Aus+ ≠> Baltic+	1.446	17.230	7.971	5.411	Aus+ ≠> Baltic+
Aus- ≠> Baltic-	56.022***	17.103	9.838	7.762	Aus- => Baltic-
Aus+ ≠> Vostochny+	5.941	19.500	9.107	6.350	Aus+ ≠> Vostochny+
Aus- ≠> Vostochny-	2.724	12.760	7.904	6.139	Aus- ≠> Vostochny-
Aus+ ≠> Sth. Africa+	14.079***	12.594	7.675	6.364	Aus+ => Sth. Africa+
Aus- ≠> Sth. Africa-	21.189***	10.182	6.353	4.713	Aus- => Sth. Africa-
Aus+ ≠> Mozambique+	4.418	17.318	8.107	6.163	Aus+ ≠> Mozambique+
Aus- ≠> Mozambique-	10.195**	13.459	8.539	6.322	Aus- => Mozambique-
Panel B: China as contributor					
China+ ≠> Aus+	14.651**	23.015	10.543	6.597	China+ = Aus+
China- ≠> Aus-	139.128***	23.015	10.543	6.597	China- => Aus-
China+ ≠> Europe+	44.975***	15.328	8.737	6.369	China+ => Europe+
China+ ≠> Europe+	45.044***	28.789	11.778	6.955	China+ => Europe+
China+ ≠> Colombia+	1.655	15.184	3.699	1.926	China+ ≠> Colombia+
China- ≠> Colombia-	1.056	16.456	4.802	1.724	China- ≠> Colombia-
China+ ≠> Baltic+	14.968**	21.265	10.534	5.752	China+ => Baltic+
China- ≠> Baltic-	12.088**	29.349	10.712	6.804	China- => Baltic-
China+ ≠> Vostochny+	45.706***	19.079	9.358	6.068	China+ => Vostochny+
China- ≠> Vostochny-	22.118***	00000	00000	00000	China- => Vostochny-
China+ ≠> Sth. Africa+	43.062***	15.384	10.024	7.936	China+ => Sth. Africa+
China- ≠> Sth. Africa-	155.942***	19.684	10.387	6.971	China- ≠> Sth. Africa-
China+ ≠> Mozambique+	25.352***	19.765	9.319	6.387	China+ => Mozambique+
China- ≠> Mozambique-	64.123***	24.031	12.752	7.604	China- => Mozambique-
Panel C: Europe as contributor					
Europe + ≠> Aus+	58.531***	15.419	8.690	6.863	Europe + => Aus+
Europe-≠> Aus-	72.542***	16.252	8.557	6.276	Europe-=> Aus-
Europe + ≠> China+	13.296**	15.478	8.289	6.141	Europe + => China+
Europe- ≠> China-	0.311	23.457	10.294	6.141	Europe- ≠> China-
Europe+ ≠> Colombia+	0.111	12.462	3.983	2.213	Europe+ ≠> Colombia+
Europe- ≠> Colombia-	0.860	16.114	8.598	6.361	Europe- ≠> Colombia-
Europe+ ≠> Baltic+	9.889**	15.041	8.610	6.775	Europe+ => Baltic+
Europe- ≠> Baltic-	41.241***	15.942	8.756	6.246	Europe- => Baltic-
Europe+ ≠> Vostochny+	10.695**	19.025	9.988	7.333	Europe+ => Vostochny+

Table 9: Asymmetric Causality Tests for Coal Prices

Null Hypothesis	Test value	Bootstrap CV at 1%	Bootstrap CV at 5%	Bootstrap CV at 10%	Conclusion
Europe- ≠> Vostochny-	16.843***	16.602	9.689	6.835	Europe- => Vostochny-
Europe+ ≠> Sth. Africa+	216.889***	13.954	9.166	6.595	Europe+ => Sth. Africa+
Europe- ≠> Sth. Africa-	137.584***	11.649	8.035	6.159	Europe- => Sth. Africa-
Europe+ ≠> Mozambique+	18.678***	14.144	8.117	6.353	Europe+ => Mozambique+
Europe- ≠> Mozambique-	58.014***	15.545	8.816	6.474	Europe- => Mozambique-
Panel D: Colombia US as contributor					
Colombia+ ≠> Aus+	0.794	15.521	5.868	3.928	Colombia+ ≠> Aus+
Colombia- ≠> Aus-	96.310***	14.021	8.635	6.427	Colombia- => Aus-
Colombia+ ≠> China+	1.474	9.287	2.781	1.658	Colombia+ ≠> China+
Colombia- ≠> China-	0.245	12.757	3.723	1.771	Colombia- ≠> China-
Colombia+ ≠> Europe+	0.038	10.621	3.124	1.775	Colombia+ ≠> Europe+
Colombia- ≠> Europe-	2.437	14.849	9.031	6.201	Colombia- ≠> Europe-
Colombia+ ≠> Baltic+	17.677**	52.979	11.396	7.103	Colombia+ => Baltic+
Colombia- ≠> Baltic-	13.199**	22.711	11.474	7.183	Colombia- => Baltic-
Colombia+ ≠> Vostochny+	0.254	8.879	3.192	1.633	Colombia-≠> Vostochny-
Colombia- ≠> Vostochny-	20.985***	17.243	9.458	6.857	Colombia- => Vostochny-
Colombia+ ≠> Sth. Africa+	2.307	12.921	7.136	4.819	Colombia+ ≠> Sth. Africa+
Colombia- ≠> Sth. Africa-	157.652***	14.062	8.163	5.754	Colombia- => Sth. Africa-
Colombia+ ≠> Mozambique+	0.304	10.371	3.366	1.790	Colombia+ ≠> Mozambique+
Colombia- ≠> Mozambique-	32.412***	17.465	8.465	6.374	Colombia- => Mozambique-
Panel E: Russia Baltic as contributor					
Baltic+ ≠> Aus+	60.981***	19.175	8.308	6.091	Baltic+ => Aus+
Baltic- ≠> Aus-	103.046***	21.541	10.378	7.765	Baltic- => Aus-
Baltic+ ≠> China+	4.600	16.928	8.979	6.604	Baltic+ ≠> China+
Baltic- ≠> China-	210.299***	30.789	7.254	5.015	Baltic- − > China-
Baltic+ ≠> Europe+	61.393***	14.053	8.158	6.201	Baltic+ => Europe+
Baltic- ≠> Europe-	95.436***	18.522	9.016	6.189	Baltic- => Europe-
Baltic+ ≠> Colombia+	2.227	41.153	13.413	6.160	Baltic+ ≠> Colombia+
Baltic- ≠> Colombia-	101.482***	20.754	9.588	6.130	Baltic- => Colombia-
Baltic+ ≠> Vostochny+	1.725	18.697	10.554	6.917	Baltic+ ≠> Vostochny+
Baltic- ≠> Vostochny-	100.611***	20.997	9.891	5.969	Baltic- => Vostochny-
Baltic+ ≠> Sth. Africa+	144.585***	14.980	9.884	8.015	Baltic+ => Sth. Africa+
Baltic- ≠> Sth. Africa-	125.449***	18.161	10.294	7.956	Baltic- => Sth. Africa-
Baltic+ ≠> Mozambique+	57.581***	16.856	8.946	6.395	Baltic+ ≠> Mozambique+

Table 9: Asymmetric Causality Tests for Coal Prices

Null Hypothesis	Test value	Bootstrap CV at 1%	Bootstrap CV at 5%	Bootstrap CV at 10%	Conclusion
Baltic- ≠> Mozambique-	46.201***	22.071	9.018	5.969	Baltic- ≠> Mozambique-
Panel F: Russia Vostochny as contributor					
Vostochny+ ≠> Aus+	182.832***	20.225	8.078	5.978	Vostochny+ => Aus+
Vostochny- ≠> Aus-	183.400***	19.314	8.444	6.172	Vostochny- => Aus-
Vostochny+ ≠> China+	10.895**	20.104	9.942	6.236	Vostochny+ => China+
Vostochny- ≠> China-	2.021	30.682	9.872	6.109	Vostochny- ≠> China-
Vostochny+ ≠> Europe+	5.512	13.677	8.621	6.258	Vostochny+ ≠> Europe+
Vostochny- ≠> Europe-	40.439***	20.677	10.067	6.773	Vostochny- => Europe-
Vostochny+ ≠> Colombia+	0.711	11.117	3.438	1.924	Vostochny+ ≠> Colombia+
Vostochny- ≠> Colombia-	22.402***	18.514	9.343	6.498	Vostochny- => Colombia-
Vostochny+ ≠> Baltic+	8.598*	24.712	9.037	5.945	Vostochny+ => Baltic+
Vostochny- ≠> Baltic-	8.349*	21.545	10.474	6.372	Vostochny- => Baltic-
Vostochny+ ≠> Sth. Africa+	48.533***	15.359	10.587	8.083	Vostochny+ => Sth. Africa+
Vostochny- ≠> Sth. Africa-	182.436***	16.027	8.266	6.301	Vostochny- ≠> Sth. Africa-
Vostochny+ ≠> Mozambique+	1.829	8.958	3.357	2.051	Vostochny+ ≠> Mozambique+
Vostochny- ≠> Mozambique-	54.004***	17.933	9.879	6.389	Vostochny- => Mozambique-
Panel G: Mozambique as contributor					
Sth. Africa+≠> Aus+	14.384***	12.541	7.571	5.892	Sth. Africa+=> Aus+
Sth. Africa-≠> Aus-	45.796***	10.313	6.575	4.549	Sth. Africa-=> Aus-
Sth. Africa+ ≠> China+	10.169**	15.785	9.730	7.684	Sth. Africa+ => China+
Sth. Africa- ≠> China-	15.767**	16.615	8.766	6.411	Sth. Africa- => China-
Sth. Africa+ ≠> Europe+	7.788	13.459	9.325	7.959	Sth. Africa+ ≠> Europe+
Sth. Africa- ≠> Europe-	2.876	11.698	8.487	6.300	Sth. Africa- ≠> Europe-
Sth. Africa+ ≠> Colombia+	0.911	12.804	7.286	4.638	Sth. Africa+ ≠> Colombia+
Sth. Africa- ≠> Colombia-	5.537	13.332	8.041	6.247	Sth. Africa- ≠> Colombia-
Sth. Africa+ ≠> Baltic+	12.176**	15.986	9.996	7.702	Sth. Africa+ => Baltic+
Sth. Africa- ≠> Baltic-	51.398***	19.197	10.603	8.514	Sth. Africa- => Baltic-
Sth. Africa+ ≠> Vostochny+	16.761***	14.626	9.612	7.986	Sth. Africa+ => Vostochny+
Sth. Africa- ≠> Vostochny-	12.653***	12.127	8.000	6.212	Sth. Africa- => Vostochny-
Sth. Africa+ ≠> Mozambique+	9.911**	14.102	9.433	7.496	Sth. Africa+ => Mozambique+

Table 9: Asymmetric Causality Tests for Coal Prices

Null Hypothesis	Test value	Bootstrap CV at 1%	Bootstrap CV at 5%	Bootstrap CV at 10%	Conclusion
Sth. Africa- ≠> Mozambique-	2.618	11.758	8.384	6.557	Sth. Africa- ≠> Mozambique-
Panel E: Sth. Africa as contributor					
Mozambique+ ≠> Aus+	80.064***	16.712	8.775	6.303	Mozambique+ => Aus+
Mozambique- ≠> Aus-	107.566***	16.720	8.639	6.816	Mozambique- => Aus-
Mozambique+ ≠> China+	18.925**	18.990	9.288	6.020	Mozambique+ ≠> China+
Mozambique- ≠> China-	1.294	22.660	10.467	6.241	Mozambique- ≠> China-
Mozambique+ ≠> Europe+	11.469**	13.428	8.117	6.412	Mozambique+ => Europe+
Mozambique- ≠> Europe-	3.054	13.823	8.528	6.531	Mozambique- ≠> Europe-
Mozambique+ ≠> Colombia+	0.561	12.488	3.243	1.800	Mozambique+ ≠> Colombia+
Mozambique- ≠> Colombia-	1.864	14.196	8.665	6.295	Mozambique- ≠> Colombia-
Mozambique+ ≠> Baltic+	3.307	15.520	9.582	7.008	Mozambique+ ≠> Baltic+
Mozambique- ≠> Baltic-	14.038**	18.283	8.992	5.978	Mozambique- ≠> Baltic-
Mozambique+ ≠> Vostochny+	1.068	8.771	3.292	2.114	Mozambique+ ≠> Vostochny+
Mozambique- ≠> Vostochny-	17.844***	15.361	10.056	6.917	Mozambique- => Vostochny-
Mozambique+ ≠> Sth. Africa+	207.943***	14.280	9.926	8.164	Mozambique+ => Sth. Africa+
Mozambique- ≠> Sth. Africa-	292.449***	12.708	8.052	6.562	Mozambique- => Sth. Africa-

Table 10: Results of trading strategies

	Strategy 1	Strategy 2	Strategy 3
Sum of weekly differences in returns between long and short positions (1)	+16.69%	+19.26%	+52.43%
Average weekly difference in returns between long and short positions (2)	+0.0229%	+0.0264%	+0.0719%
Weekly standard deviation of the long-short strategy returns (3)	2.93%	2.92%	3.95%
Ratio: (1) / (3)	5.70	6.59	13.28

Note: (1) Strategy 1 relies on all markets in the sample. Long positions are opened in the coal prices of all net-recipients (China, Europe, Colombia, RussiaBaltic, Russia Vostochny and Mozambique) and short positions are opened in all markets of net-contributors (Australia and South Africa). All markets are equally weighted within these two groups.

(2) Strategy 2 is also based on all markets in the sample. Longpositions are opened in the coal prices of all net-recipients, while short positions are opened in all markets of net-contributors. The weights are allocated according to the value of their contribution within each group.

(3) Strategy 3 extracts only the markets, which are the strongest influencer (Australia) and the most sensitive recipient (China). In this case, long position is opened in the coal price in China and it is hedged by a short position in the coal price in Australia.

Figure 1: Total Spillover Index - Price

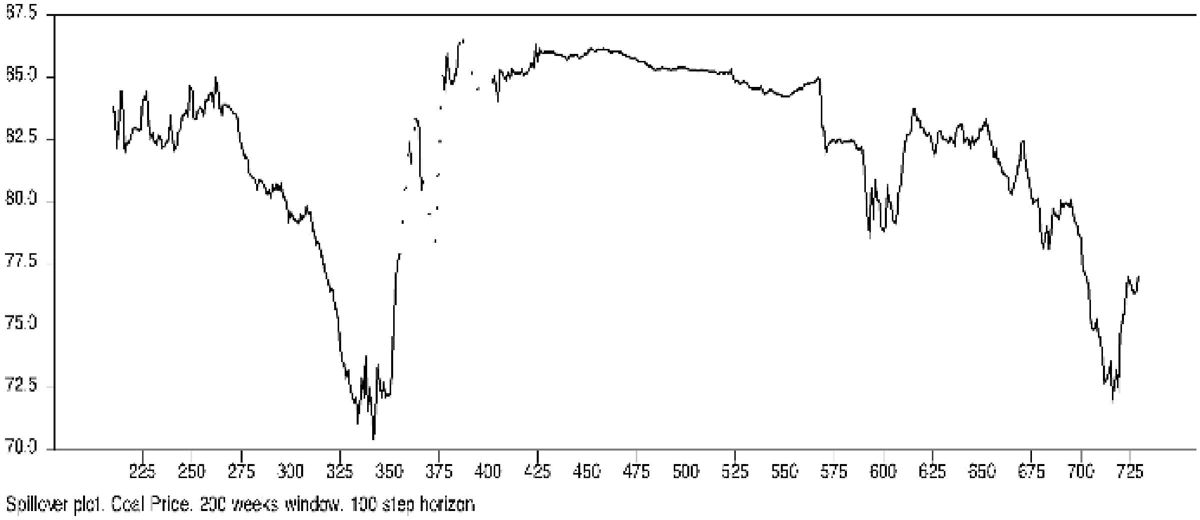


Figure 2: Total Spillover Index - Volatility

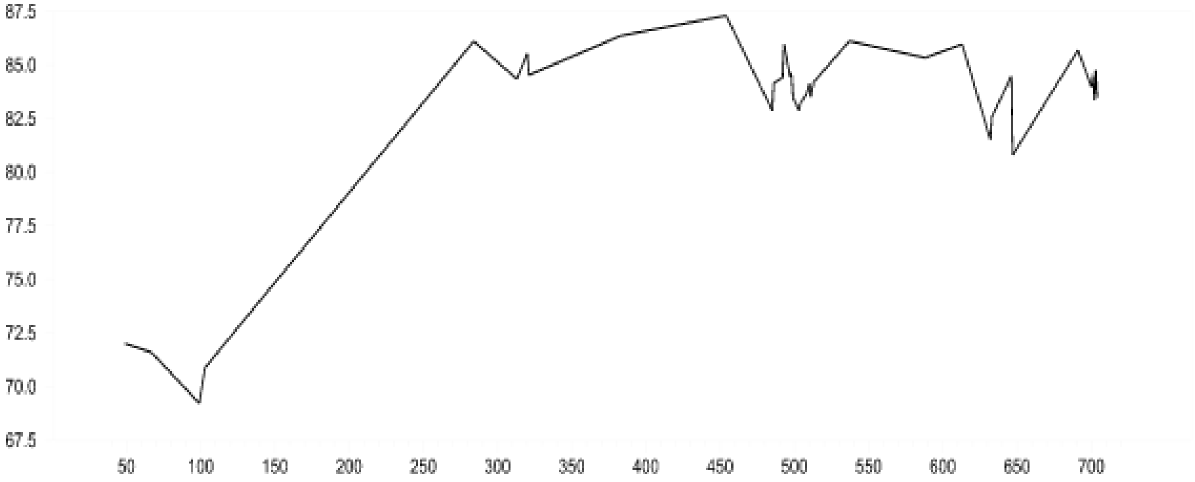


Figure 3: Dynamic frequency connectedness - Australia

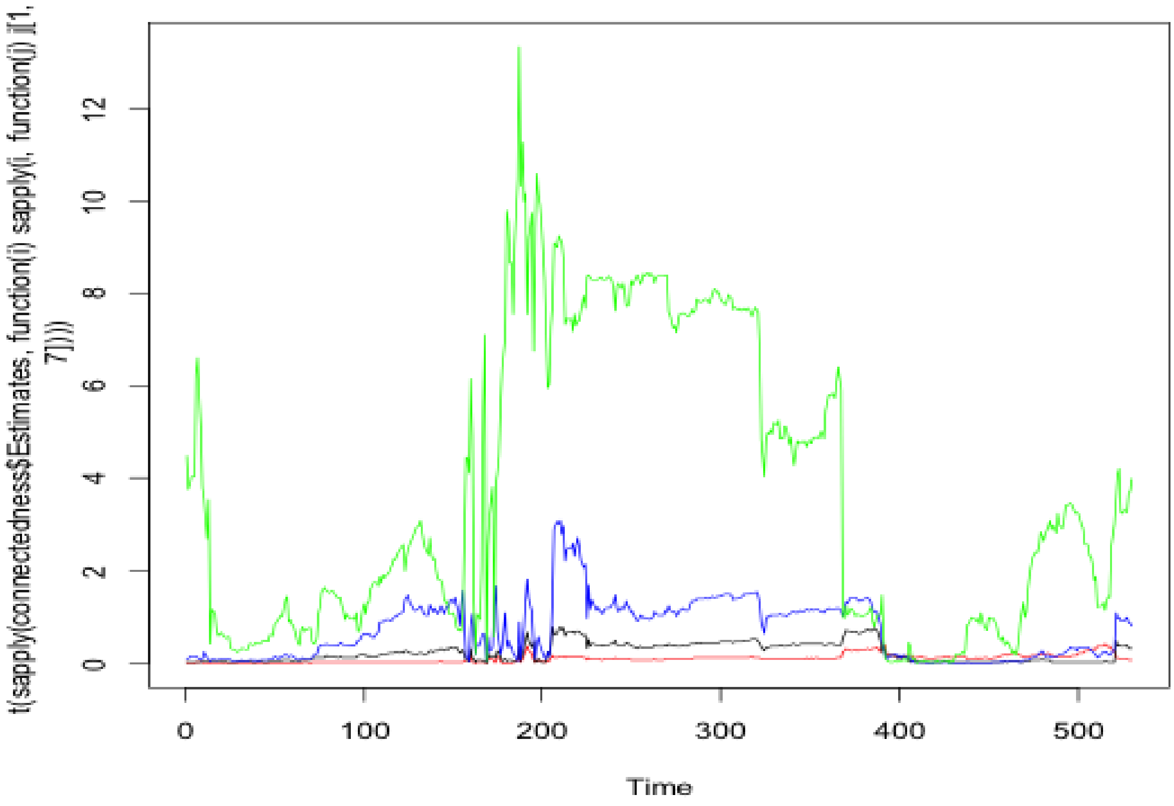


Figure 4: Dynamic frequency connectedness - Mozambique

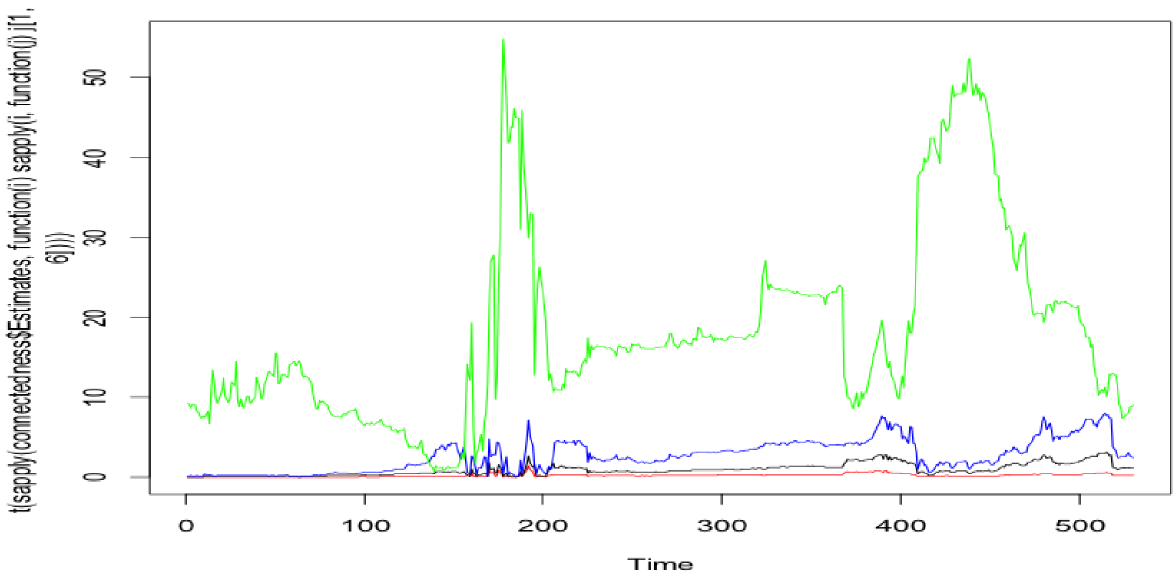


Figure 5: Dynamic frequency connectedness - China

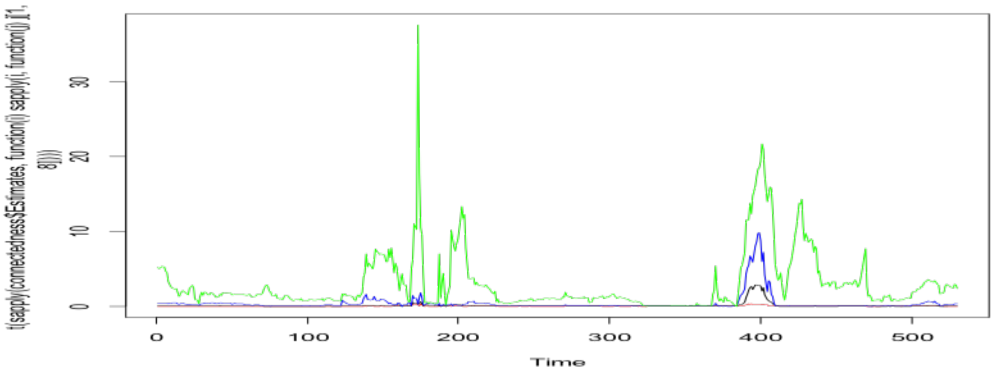


Figure 6: Dynamic frequency connectedness - coba

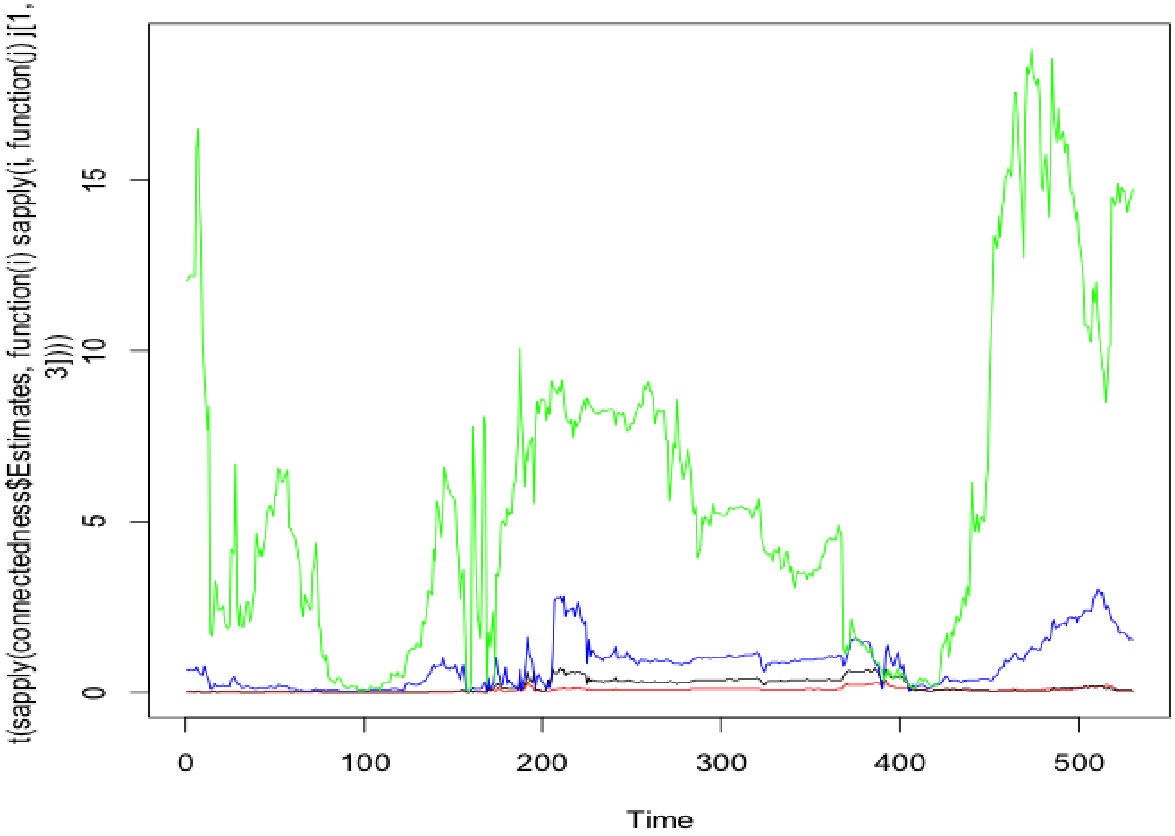


Figure 7: Dynamic frequency connectedness - cobu

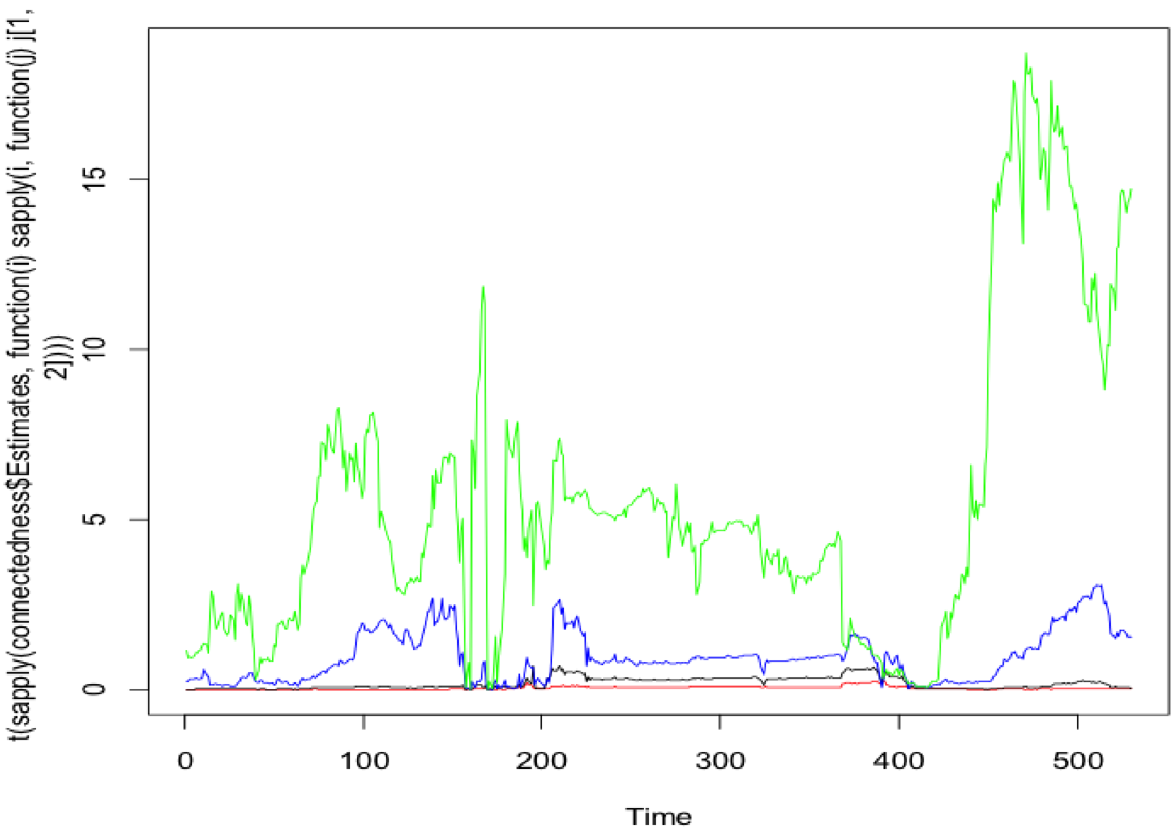


Figure 8: Dynamic frequency connectedness - Baltic

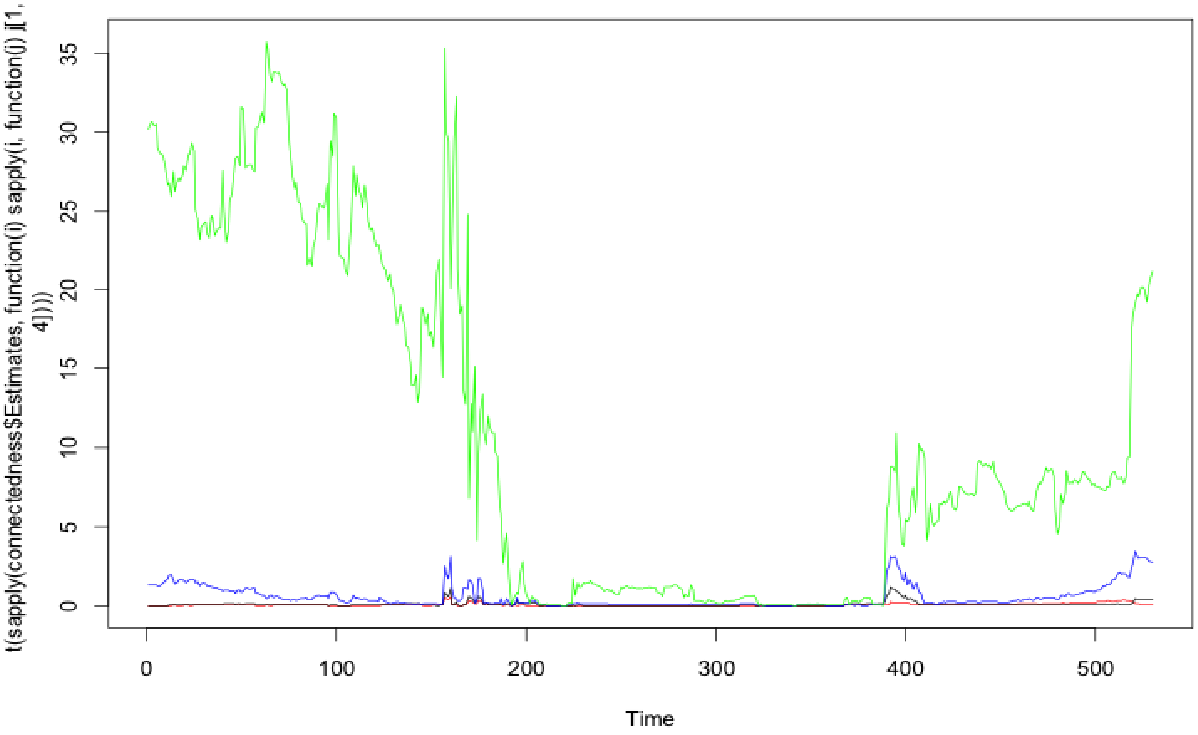


Figure 9: Dynamic frequency connectedness - Russia

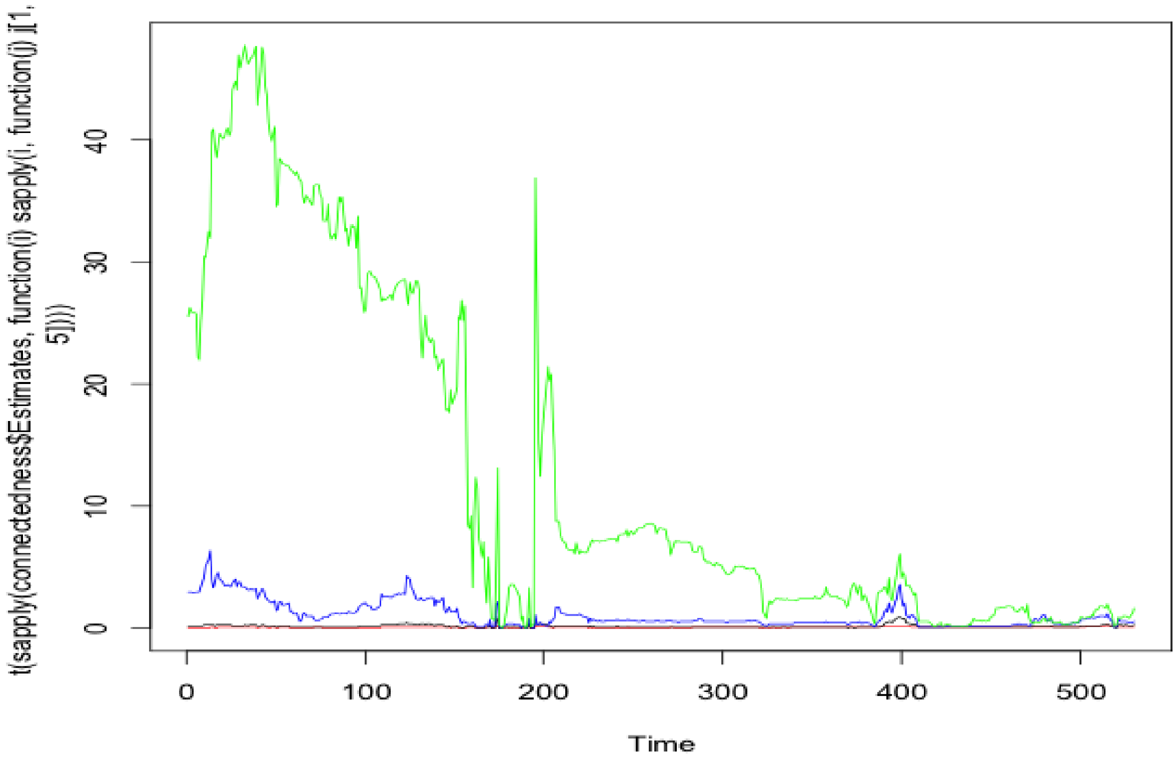


Figure 10: Directional Price Spillovers - From Others

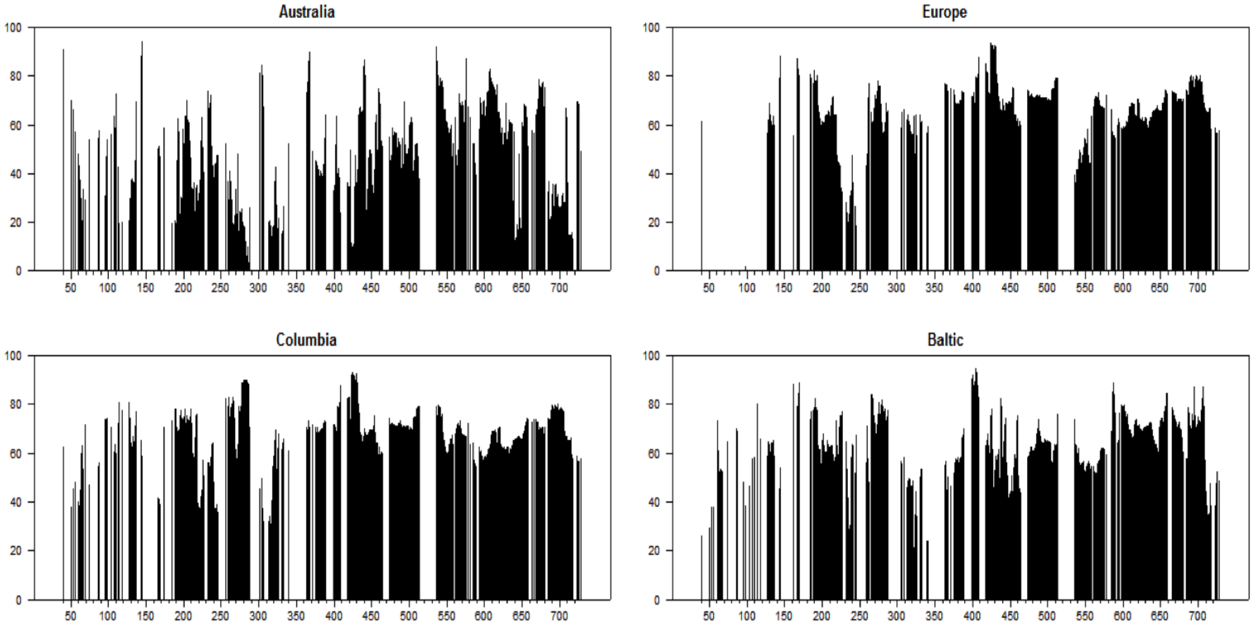


Figure 11: Directional Price Spillovers - From Others 2

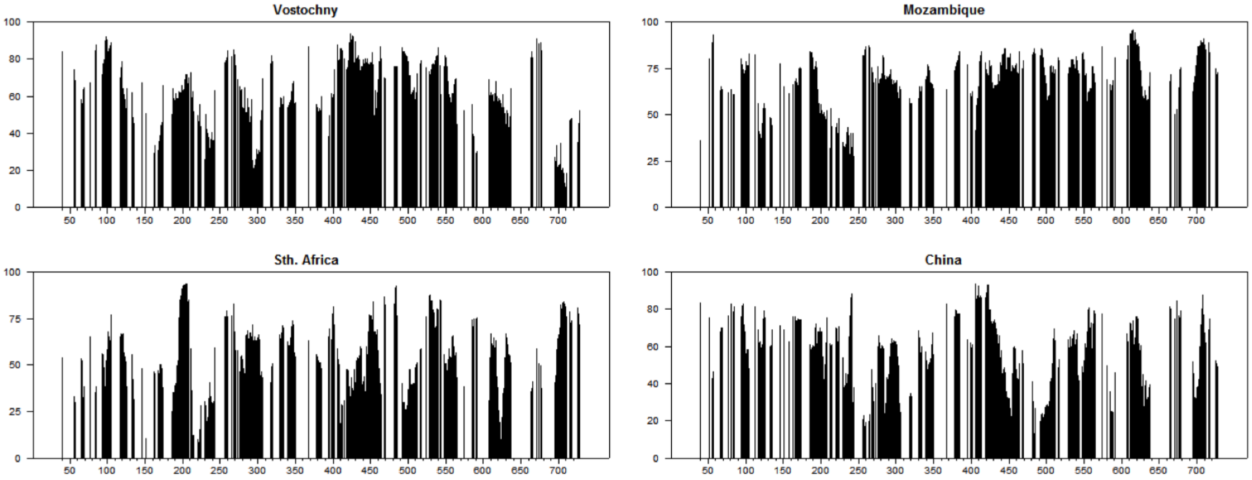


Figure 12: Directional Price Spillovers - to Others

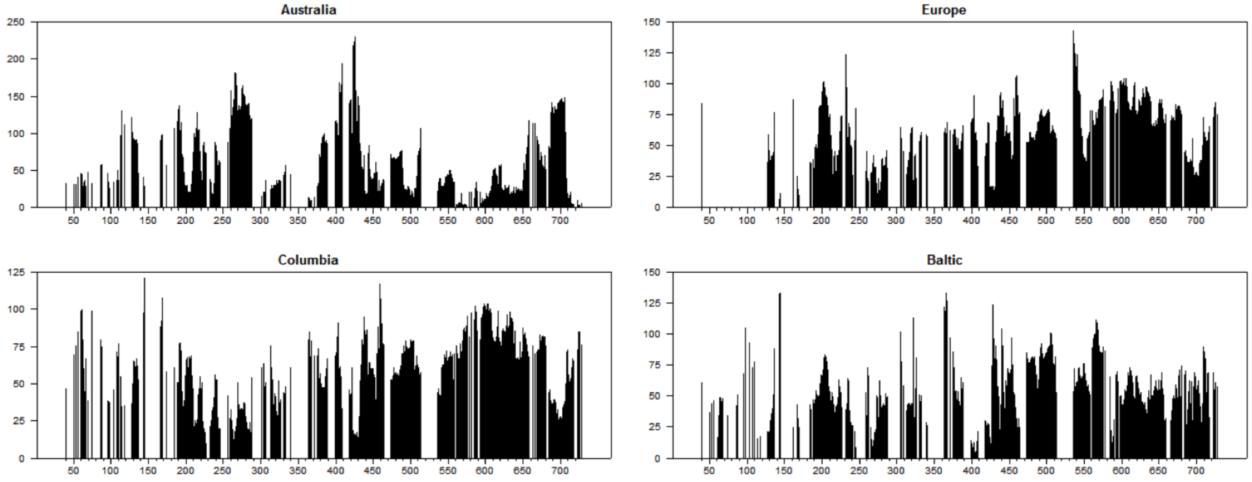


Figure 13: Directional Price Spillovers - to Others 2

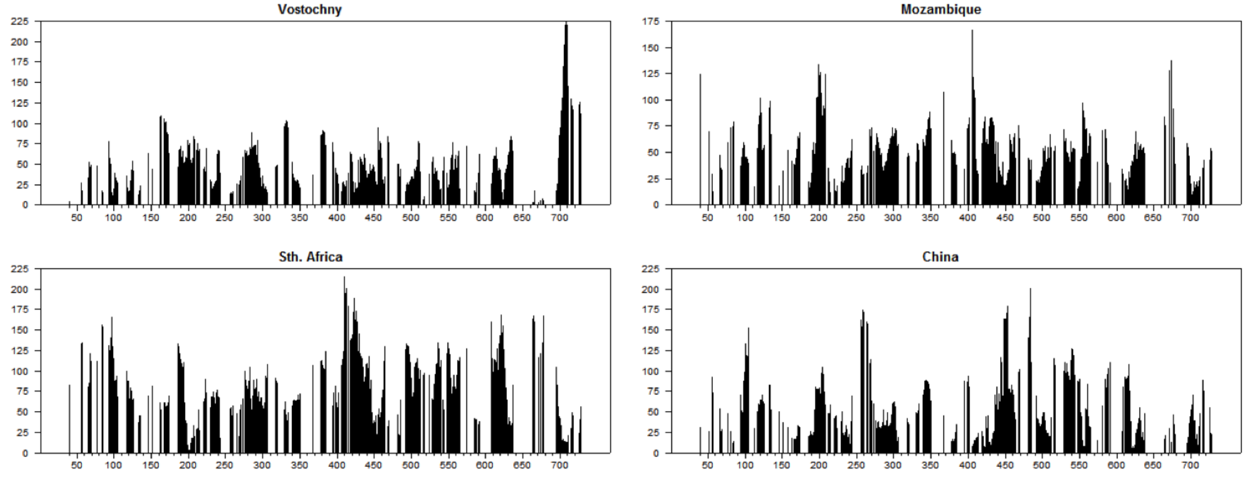


Figure 14: Directional Volatility Spillovers - From Others

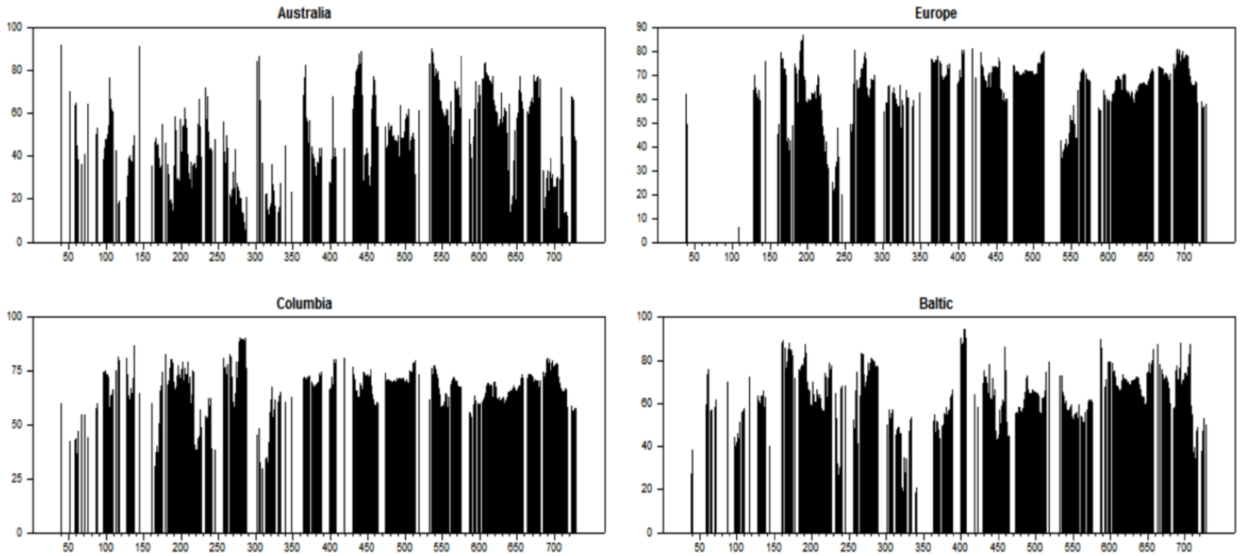


Figure 15: Directional Volatility Spillovers - From Others 2

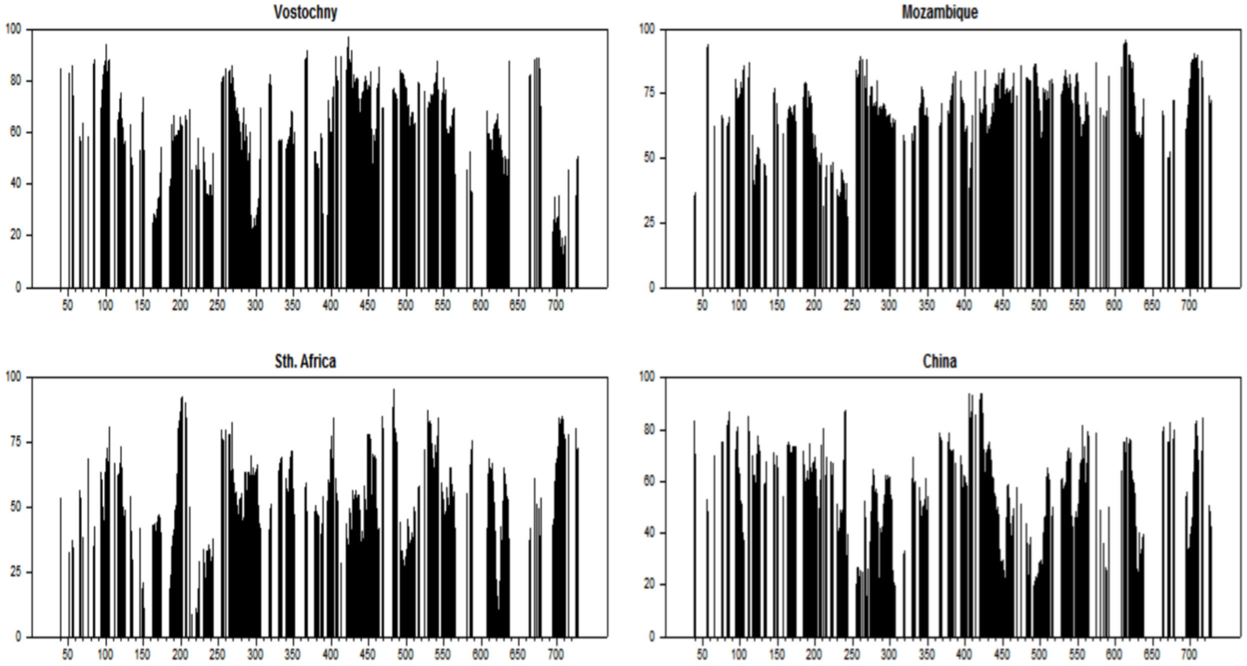


Figure 16: Directional Volatility Spillovers - to Others

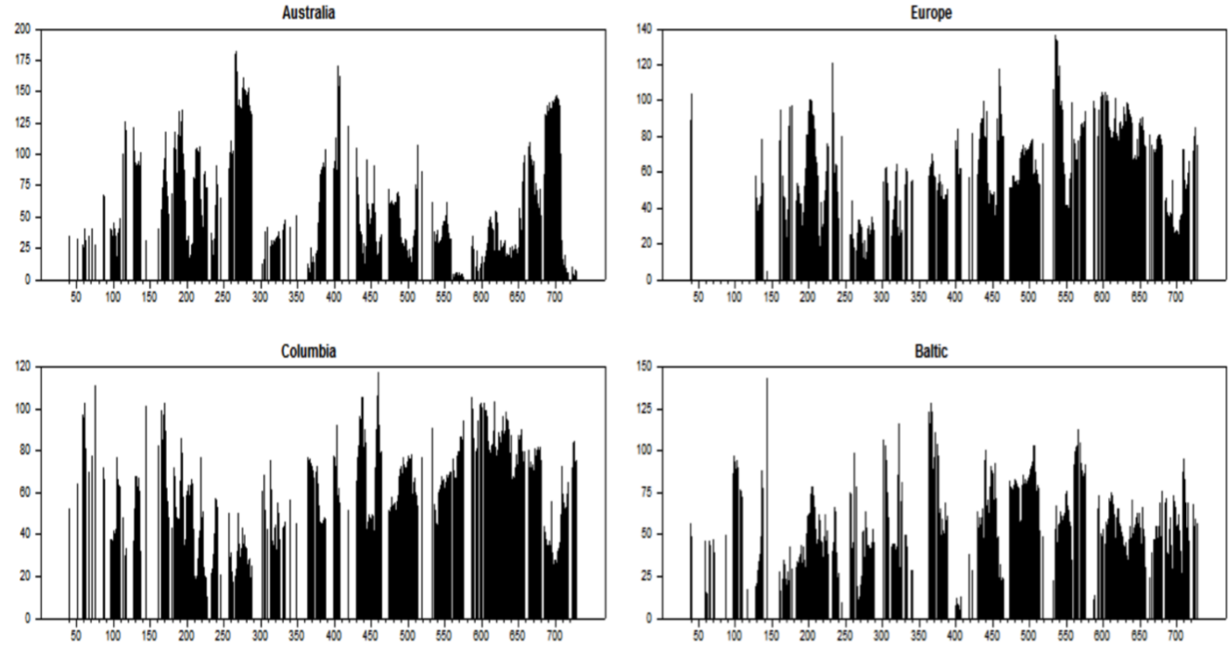
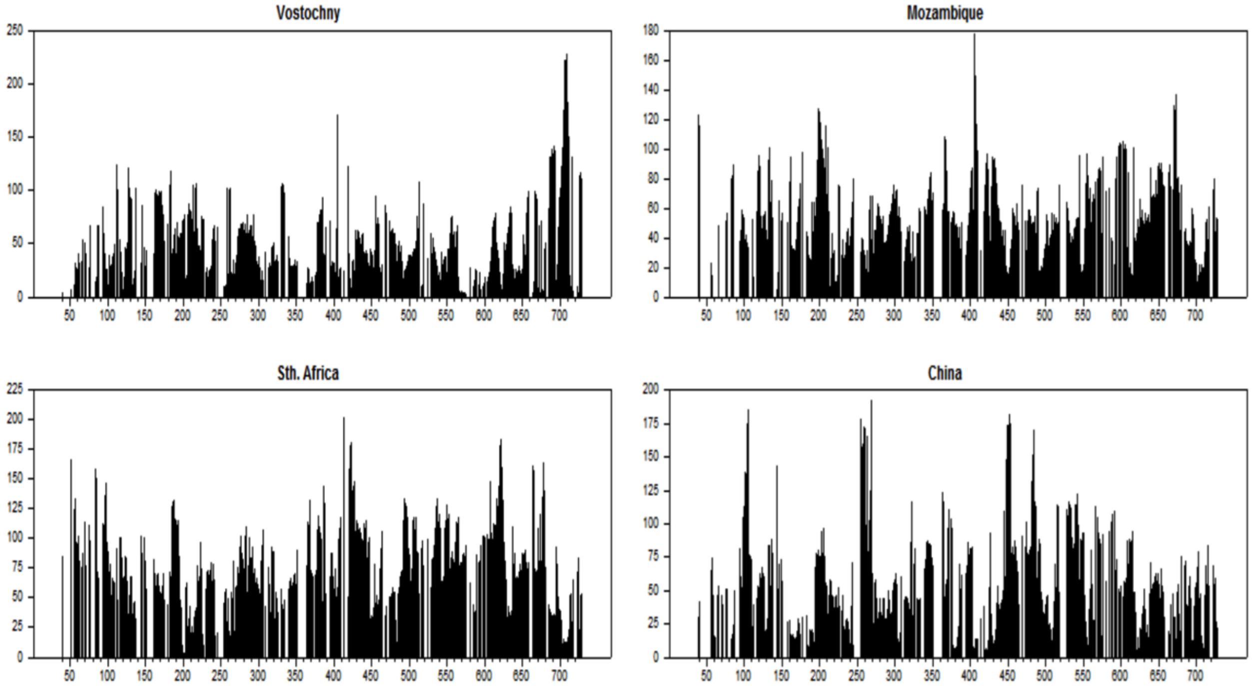


Figure 17: Directional Volatility Spillovers - to Others 2



Highlights

- We examine the global steam coal market
- Australian market remains the dominant force in setting world coal prices,
- the market responds to shocks in a symmetric manner
- The market is highly integrated
- China is the largest source of vaolatility

Data

All data are sourced from Bloomberg, as per description in the paper. As such they are propriatory and we cannot provide “ad lib”. We are perfectly happy to send data to reviewers etc on request of course

Frequency Domain codes

```
#First load packages and get some data.

library(vars)

library(urca)

library(frequencyConnectedness)

data(exampleSim)

#test.csv <- read.csv("C:/Users/dlgh7/Dropbox/Marco/JanuszandBrian/frequencyConnectedness/coalexcel.csv", header=T)

#test.stata <- read.dta("d:/test.dta")

#Then compute a system estimate on which the computation of connectedness is based:

# Shorten the data, rolling estimation takes quite some time

#exampleSim <- exampleSim[1:600,]

# Compute the VAR(2) estimate with constant and save results

est <- VAR(exampleSim, p = 2, type = "both")

# Alternatively, you could use VECM

# est <- vec2var(ca.jo(exampleSim, ecdet = "trend", K = 2), r = 1)



###################Next, we can decompose the measure on desired frequencies and get the frequency dependent measures.###########################################

# Get the frequency connectedness on partition (pi,pi/2), (pi/2, pi/4), (pi/4,0)

bounds <- c(pi + 0.0001, pi/c(4, 12, 48), 0) # The 1.001 has to be there because otherwise it is an open interval

#spilloverBK09(est, n.ahead = 100, partition = bounds, absolute = T, no.corr = F)

spilloverBK12(est, n.ahead = 100, partition = bounds, absolute = T, table=TRUE, no.corr = F)
```

```
##################################################################################
#################

# Both absolute and within connectedness can produce tables with parameter table = T

#Note that the bounds should cover the range (1.001, 0)*pi, because the overall variance of the system is computed over these frequencies. (So if you wanted to remove the trend from computations, you could use (1.001, 0.01)*pi and the computation will ignore the variance created around the zero frequency.)

#In many cases, one is interested in the dynamics of the connectedness. This can be achieved within the package by the following commands. (The parameters correspond to the VAR parameters from the vars package. Dynamic computation of connectedness with co-integration is not implemented in the package but is rather straightforward to do, see other examples.)

# Get rolling window estimates

spilloverRollingBK12(exampleSim, p = 2, type = "both", window = 200, n.ahead = 100, no.corr = F, partition = bounds, absolute = T)

spilloverRollingBK12(exampleSim, p = 2, type = "both", window = 200, n.ahead = 100, no.corr = F, table = T, partition = bounds, absolute = T)
```

The function spilloverRollingBK12 (or implementation of rolling estimation of other connectedness schemes) contains a parameter switch named table which is by default FALSE. If turned true, the rolling estimation returns a list which entry is the same as the value of spilloverBK12 with the same parameter on the corresponding window of the data. For example, if we wanted to look at element 2,1 of the connectedness in the standard case

```
connectedness <- spilloverRollingDY12(exampleSim, p = 2, type = "both", window = 200, n.ahead = 100, no.corr = F, table = TRUE)

plot(sapply(connectedness, function(i) i[4,4]), type="l")

#In case we wanted the same information disaggregated over frequencies, we can use

connectedness <- spilloverRollingBK12(exampleSim, p = 2, type = "both", window = 200, n.ahead = 100, no.corr = F, table = T, partition = bounds, absolute = T)


plot.ts(t(sapply(connectedness$Estimates, function(i) sapply(i, function(j) j[1,5]))), plot.type = "single", col = c("red","black","blue","green"))


#t(sapply(connectedness$Estimates, function(i) sapply(i, function(j) j[1,3])))

#plot.ts(t(sapply(connectedness$Estimates, function(i)  sapply(i, function ( j ) j[2,3]))), plot.type = "single", lty = 1:4)

# 0=blank, 1=solid, 2=dashed, 3=dotted, 4=dotdash, 5=longdash, 6=twodash
```

```
* Replication file for Diebold and Yilmaz(2012), "Better to give than to receive:
* Predictive directional measurement of volatility spillovers," International
* Journal of Forecasting, vol. 28, no 1, 57-66.
*
open data coalpriceln.xls
data(format=xls,org=columns,right=9) 1 729 AUNE	COBA	COBU	RUBA	RUVO	SARB SAMA	CHQI

*
dec hash[string] shorthash longhash
compute shorthash("AUNE")="Australia",$
	longhash("AUNE")="Australia"
compute shorthash("COBA")="Columbia",$
	longhash("COBA")="Columbia"
compute shorthash("COBU")="Europe",$
	longhash("COBU")="Europe"
compute shorthash("RUBA")="Baltic",$
	longhash("RUBA")="Baltic"
compute shorthash("RUVO")="Vostochny",$
	longhash("RUVO")="Vostochny"
compute shorthash("SARB")="Sth. Africa",$
	longhash("SARB")="Sth. Africa"
compute shorthash("SAMA")="Mozambique",$
	longhash("SAMA")="Mozambique"
compute shorthash("CHQI")="China",$
	longhash("CHQI")="China"
*
* spgraph(vfields=4,hfields=2,$
* header="Figure 1. Weekly Coal Markets Volatilities",$
```

```
* subheader=" ")
* dofor i = AUNE        COBA    COBU    RUBA    RUVO    SARB SAMA CHQI
*    set ann_std_dev = 100*sqrt(365*i{0})
*    graph(header=longhash(%l(i)))
*    # ann_std_dev
* end dofor i
* spgraph(done)
*
*dofor i = AUNECOBA    COBU    RUBA    RUVO    SARB SAMA CHQI
*  set i = log(i{0})
*end do i
*
*table / AUNE   COBA    COBU    RUBA    RUVO    SARB SAMA CHQI


*
* 4 lag VAR
* 10 step responses
* use GIRF's
*
compute nlags=4
compute nsteps=10
compute usegirf=1
*
system(model=assetvar)
variables AUNE  COBA    COBU    RUBA    RUVO SARB SAMA CHQI
lags 1 to nlags
det constant
end(system)
*
estimate
*
```

```
compute rstart=%regstart(),rend=%regend()
*
dec vect[string] shortlabels(%nvar) longlabels(%nvar)
ewise shortlabels(i)=shorthash(%l(%modeldepvars(assetvar)(i)))
ewise longlabels(i)=longhash(%l(%modeldepvars(assetvar)(i)))
*
**********************************************************************
*
* Produce the appropriate "factor" matrix from %sigma
*
function FactorMatrix
type rect FactorMatrix
if usegirf
   compute FactorMatrix=%sigma*inv(%diag(%sqrt(%xdiag(%sigma))))
else
   compute FactorMatrix=%decomp(%sigma)
end
**********************************************************************
compute gfactor=FactorMatrix()
errors(model=assetvar,steps=nsteps,factor=gfactor,stderrs=gstderrs,noprint,results=gfevd)
compute gfevdx=%xt(gfevd,nsteps)
*
* These are for computing the contributions from others, to others and
* to others including own for each variable.
*
dec vect tovar(%nvar) fromvar(%nvar) tototal(%nvar)
ewise fromvar(i)=%sum(%xrow(gfevdx,i))-gfevdx(i,i)
ewise tovar(i)=%sum(%xcol(gfevdx,i))-gfevdx(i,i)
ewise tototal(i)=tovar(i)+1-fromvar(i)
compute spillover=100.0*%sum(tovar)/%nvar
*
```

```
report(action=define,title="Table 2. Volatility Spillover Table, Coal markets")

report(atrow=1,atcol=2,align=center,fillby=rows) shortlabels

report(atrow=2,atcol=1,fillby=cols) shortlabels

report(atrow=2,atcol=2) 100.0*gfevdx

report(atrow=%nvar+2,atcol=1,fillby=rows) "Contribution to others" 100.0*tovar

report(atrow=%nvar+3,atcol=1,fillby=rows) "Contribution including own" 100.0*tototal

report(atcol=%nvar+2,atrow=1) "From Others"

report(atcol=%nvar+2,atrow=2,fillby=cols) 100.0*fromvar

report(atrow=%nvar+2,atcol=%nvar+2,fillby=cols) 100.0*%sum(tovar)

report(atrow=%nvar+3,atcol=%nvar+2,align=right) %strval(spillover,"##.#")+"%"

report(atrow=2,atcol=2,torow=%nvar+1,tocol=%nvar+1,action=format,picture="*.##")

report(atrow=%nvar+2,torow=%nvar+3,atcol=1,tocol=%nvar+2,action=format,picture="###.#")

report(atcol=%nvar+2,atrow=2,torow=%nvar+2,action=format,picture="###.#")

report(action=show)

*

* Rolling sample analysis

*

compute nspan=36

*

dec series totalspill

dec symm pairvar(%nvar,%nvar)

dec vect[series] fromspill(%nvar) tospill(%nvar) netspill(%nvar)

dec symm[series] pairspill(%nvar,%nvar)

clear(zeros) fromspill topspill totalspill netspill pairspill

*

do end=rstart+nspan-1,rend

  estimate(noprint) end-nspan+1 end

  *

  * Skip any data points where the rolling VAR has an explosive root.

  *

  eigen(cvalues=cv) %modelcompanion(assetvar)
```

```
   if %cabs(cv(1))>=1.0 {
      compute totalspill(end)=%na
      next
   }
   compute gfactor=FactorMatrix()
   errors(model=assetvar,steps=nsteps,factor=gfactor,noprint,results=gfevd)
   compute gfevdx=%xt(gfevd,nsteps)
   ewise tovar(i)=%sum(%xcol(gfevdx,i))-gfevdx(i,i)
   ewise fromvar(i)=%sum(%xrow(gfevdx,i))-gfevdx(i,i)
   ewise pairvar(i,j)=gfevdx(i,j)-gfevdx(j,i)
   compute totalspill(end)=100.0*%sum(tovar)/%nvar
   compute %pt(fromspill,end,100.0*fromvar)
   compute %pt(tospill,end,100.0*tovar)
   compute %pt(netspill,end,100.0*(tovar-fromvar))
   compute %pt(pairspill,end,100.0*pairvar)
end do end
*
graph(header="Figure 3. Total Volatility Spillovers")
# totalspill rstart+nspan-1 rend
*
spgraph(vfields=4,hfields=4,$
  header="Figure 4. Directional Volatility Spillovers, FROM others")
 do i=1,%nvar
   graph(header=longlabels(i),style=bar)
   # fromspill(i) rstart+nspan-1 rend
 end do i
spgraph(done)
*
spgraph(vfields=4,hfields=2,$
  header="Figure 5. Directional Volatility Spillovers, TO others")
 do i=1,%nvar
```

```
   graph(header=longlabels(i),style=bar)
   # tospill(i) rstart+nspan-1 rend
 end do i
spgraph(done)
*
*
spgraph(vfields=7,hfields=8,$
  header="Figure 7. Net Pairwise Volatility Spillovers")
  do i=1,%nvar
     do j=i+1,%nvar
        graph(header=shortlabels(i)+"—"+shortlabels(j),style=bar)
        # pairspill(i,j)
     end do j
  end do i
spgraph(done)

* To produce a high re the net pairwise volatility spillovers graphs for all 56 possible market
combinations use the following approach:

*spgraph(vfields=7,hfields=8,$
*header="Figure 7. Net Pairwise Volatility Spillovers")
*do i=1,%nvar
*    do j=i+1,%nvar
*      graph(header=shortlabels(i)+"—"+shortlabels(j),style=bar)
*       # pairspill(i,j)
*     end do j
*  end do i
* spgraph(done)
*
```

Wavelet Codes are those of the BIWAVELET package in r.