Elucidating the Relationship among EUA Spot Price, Brent Oil Price and Three European Stock Indices

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This study examines the long-term equilibrium relationship among European Union Allowance (EUA) spot price, Brent oil price and three European stock indices from January 1, 2005 to Dec. 31, 2012, and is divided into three sub-periods: 2005 to 2007 (Volatility Index (VIX) stable period), 2008 to 2010 (i.e., US subprime loan crisis and VIX rising periods), and 2011 to 2012 (i.e., European debt crisis, also VIX rising period). Several notable findings from the empirical studies are presented. First, the long-term equilibrium relationship does not exist for the full sample period, the first and third sub-periods. However, EUA spot and oil prices, and DAX index are co-integrated with each other during the second sub-period. Although oil price can be adjusted to the long-term equilibrium in German stock market during that period, adjusting EUA spot price to long-term equilibrium is rather difficult. Next, oil price is affected by EUA spot price unilaterally for the full sample period and the third sub-period. Moreover, EUA spot price is unaffected by any factor except itself during the first sub-period, and is affected by three European stock indices for the full sample period, and the third sub-period. Meanwhile, oil price is unaffected by any factor during the first sub-period. Finally, variance decomposition analysis results indicate that the most explanatory power for oil Brent and EUA spot prices arising from themselves, respectively.

JET Codes: D53 and G15

1. Introduction

Industrialized revolution has, since the 19th century, dramatically transformed production and economic activities. Humans consume large quantities of oil,
coal and natural gas for production, all of which are non-renewable. For instance, oil adversely impacts the production, all of which are non-renewable. For instance, oil adversely impacts the environment, as evidenced by the Greenhouse effect that contribute to global warming.

Initially approved on December 11, 1997 to set anthropogenic greenhouse gas (GHG) emission reduction targets for individual nations, the Kyoto Protocol was enacted on February 16, 2005. Seven years later, during Doha climate change talks held on December 8, 2012, 37 countries recommitted their efforts to reduce GHG emissions 21% below than 1990 level from January 1, 2013 to December 31, 2020. However this treaty covers only 15% of the GHGs worldwide.

To comply with Kyoto Protocol requirements, the European Union Emissions Trading Scheme (EU ETS) was launched in 2005 as the first large emissions trading scheme worldwide. As of 2013, the EU ETS covers more than 11,000 factories, power stations, and other facilities that have a net heat in excess of 20MW in 31 countries. However, CO₂ emissions are closely related to non-renewable energy sources. The countries that own the installations are allocated a number of allowances called European Union Allowances (EUA). Each EUA gives the owner the right to emit one ton of CO₂. EUA, are tradable emissions credit from the EU ETS. Kanen (2006) asserted that, although the Brent oil price significantly impacts natural gas prices, yet fluctuations in natural gas affect electricity price and, ultimately, carbon price. Restated, an increasing energy demand raises both energy prices and CO₂ emissions, subsequently increasing EUA spot prices (Alberola et al., 2008). Mansanet-Bataller et al. (2007) also found that energy sources play a major role in determining EUA spot prices, especially from natural gas and Brent oil prices.

Along with globalization, individual countries mutually impacts each other. Additionally, the latest information is transmitted rapidly from the capital markets to commodity markets, suggesting that the former are closely related to the latter. Therefore, Chevallier (2009) found that EUA spot price can be forecasted based on the stock and bond markets. Bredin and Muckley (2011) posited that the EUA spot price is integrated with the stock market. Since most previous literatures examined the correlation between EUA spot and energy prices or that between EUA spot price and stock index for an individual country, this study examines the relationship among EUA, and Brent oil spot price and the
stock indices of Germany, France and the United Kingdom from March 9, 2005 to December 31, 2012 in order to serve as a valuable reference for asset allocation and hedging purposes. This investigation selects March 9, 2005 as the starting date. Since the first transaction on EUA spot price was made on March 9, 2005.

This study focuses on the following objectives: examine the causality among the Brent oil price, EUA spot price and three European stock indices; investigate whether there is a long-term equilibrium relationship among oil and EUA spot price and three European stock indices and its adjustment speed; and explore the explanatory power of the impact of oil and EUA spot prices as well as three European stock indices on oil and EUA spot prices.

2. Literature Review

This study classifies previous literatures into related studies on the correlation between oil price and stock market index and previous research on the correlation between energy and carbon prices.

As for studies on oil and stock prices or stock market index, El-Sharif et al. (2005), Oberndorfer (2009) and Arouri (2011) all found that significant correlations between crude oil and energy stock prices; while Basher and Sadorsky (2006), Park and Ratti (2008), Lee and Zeng (2011), Creti et al. (2012) and Wang et al. (2013) all found significant correlations between oil and stock prices in the U.S. and European markets.

As for research regarding the correlation between energy and carbon prices, Mansanet-Bataller et al. (2007), Hu and Liao (2013) and Reboredo (2013) observed that energy prices correlated significantly with the carbon prices. However, Bredin and Muckley (2011) found that carbon prices achieved cointegration with stock prices.

3. The Methodology and Model

The EUA spot price, Brent oil price and three European stock indices were used as the research targets from March 9, 2005 to December 31, 2012. 1,855 pieces of data are available daily. Owing to that European Energy Exchange (EEX) has offered trading of EUA on the basis of EU UTS since March 9, 2005 (i.e. the earliest among EEX, ICE European Climate Exchange (ECX),
NordPoor (Now owned by NASDAQ) and Bluenx exchanges), this study selects the EUA spot price from EEX. Meanwhile, Brent oil spot price daily data was gathered from U.S. Energy Information Administration (EIA). Additionally, three European Stock Indices (i.e. FTSE 100 Index (FT100), CAC 40 Index (CAC), and Deutsche Borse AG German Stock Index (DAX) are collected from the Taiwan Economic Journal (TEJ).

### 3.1 ADF test

While intended for a unit root in a time series sample, an augmented Dickey-Fuller (ADF) test is a scaled-up version of the Dickey-Fuller test for a larger and more complicated set of time series models. The ADF statistic is a negative number. A more negative number implies stronger rejection of the hypothesis that there is a unit root at some level of confidence. The ADF model is as follows:

\[
\Delta Y_t = \alpha_0 + \delta Y_{t-1} + \gamma T + \sum_{i=2}^{\rho} \rho_i \Delta Y_{t-i+1} + \epsilon_t,
\]

where \(\Delta Y_t\) denotes the first-order difference of the logarithmic series; \(\alpha_0\) is a constant; \(T\) refers to a time trend; \(n\) is the lag term; \(\delta, \gamma, \) and \(\rho_i\) denote the coefficients; and \(\epsilon_t\) represents a white noise term in the hypothesis \(H_0: \delta = 0\). Failure to reject the null hypothesis implies a unit root if a regime shift such as an oil shock occurs and is required to cause some-order difference functions to become stationary.

### 3.2 Co-integration Test and Vector Error Correction Model

The co-integration test is a statistical feature of time series variables. Wang et al. (2013) contended that non-stationary variables can become stationary ones through linear combination with one another (i.e. non-stationary variables have a long-term equilibrium relationship among variables). Even if such variables depart from the equilibrium relationship owing to short-term external disruptions, the degree of variation of the variables eventually decreases and returns to a general equilibrium. Based on the maximum likelihood estimation (MLE) of the Johansen (1988) test, this study examines whether co-integration exists among variables as well as determines the number of co-integration vector groups. The MLE method is as follows:

\[
Z_t = \mu + A_1 Z_{t+1} + \cdots + A_p Z_{t-p} + \epsilon_t,
\]

where \(Z_t\) is a matrix of \(n \times 1\), i.e. the internal variable of lag \(p\) term. Equation (2) is then rewritten using the first-order difference function to obtain a
vector error correction model (VECM):

$$\Delta Z_t = \mu + \Pi Z_{t-1} + \Sigma_{i=1}^{p-1} \Gamma_i \Delta Z_{t-1} + \epsilon_t,$$

where $\Pi = \sum_{i=1}^{p} A_i I$; $\Gamma_i = -\left(\sum_{i=2}^{p-1} A_i\right)$, $p$ is the lagged term, and $I$ is an identity matrix.

Equation (3) denotes a VAR model with first-order difference plus an error correction item ($\Pi Z_{t-1}$), where $\Gamma_i$ represents the short-term dynamic information, and the matrix refers to long-term relevant information.

Consequently, $\Pi$ denotes a long-term impact matrix, and the number of the co-integration vectors is determined using the rank of $\Pi$ matrix. There are three possibilities:

1. Rank ($\Pi$) = $k$, implying that all variables in $Z_t$ vectors are stationary time series.
2. Rank ($\Pi$) = 0, implying that all variables are stationary time series after performing the first-order difference function, and the variables do not have co-integrating relationship (i.e., no long-term equilibrium relationship).
3. Rank ($\Pi$) = $r$, and 0 < $r$ < $k$, implying that the variables in $Z_t$ vectors have $r$ co-integrating relationships.

According to Granger’s representation theorem, $\Pi = (\alpha \beta')$, where $\alpha$ and $\beta$ are $n \times r$, and $r < n$; $\alpha$ is a matrix of adjustment coefficient, and $\beta$ is a co-integrated matrix and $\alpha \beta'$ refers to the coefficient matrix of the adjustment speed of error correction from off-balance to long-term equilibrium. If $\alpha > 0$, indicating the error of underestimation, which adjusts itself upward by a specific speed to the next term; If $\alpha < 0$, implying the error of overestimation, which adjusts itself downward by a specific speed to the next term.

Johansen and Juselius (1990) proposed two tests for the number $r$ of co-integrating reectors: Trace test and the Maximum Eigenvalue Test. This study uses the Trace test as Lutkepohl et al. (2001) found that the powers of the corresponding trace and maximum eigenvalue tests are very similar.

Based on the log-likelihood ratio $\ln\left[\frac{L_{max}(r)}{L_{max}(k)}\right]$, trace test is conducted sequentially for $r = k-1, ..., 1, 0$. This test examines the null hypothesis that the co-integration rank equals $r$ against the alternative that the rank equals $k$. The latter implies that $X_t$ is trend stationary. We thus hypothesize the following:

$H_0$: rank $\Pi \leq r$, for the most $r$ groups of co-integration vectors;

$H_1$: rank $\Pi > r$, for the least $r$ groups of co-integration vectors.

The trace test statistics are calculated as follows:
\[
\lambda_{trace} = -T \sum_{t=r+1}^{n} \ln(1 - \hat{\lambda}_t),
\]

where \( \lambda_{trace} \) denotes the statistical value of Johansen trace test; \( \hat{\lambda}_t \) represents the estimated value of the \( i \)th eigenvalues; \( T \) refers to the number of samples; \( n \) denotes the number of Eigenvalues that obey the Chi-square distribution under examination.

### 3.4 Vector Autoregression Model

As a statistical model of linear interdependence among multiple time series. The vector autoregression (VAR) model generalizes the univariate autoregression (AR) model by allowing for multiple evolving variables. A VAR model comprises a set of \( k \) time series regressions, in which the regressors are lagged values of all \( k \) series.

\[
Z_t = \mu + A_1 Z_{t-1} + \ldots + A_p Z_{t-p} + \varepsilon_t,
\]

where \( Z_t \) denotes a parameter matrix of \( n \times 1 \), \( \mu \) represents an intercept matrix of \( n \times 1 \); \( A_i \) refers to a coefficient matrix of \( n \times n \); \( p \) denotes the number of the lagged terms; and \( \varepsilon_t \) is the white noise matrix.

VAR models have two restrictions: time series are stationary, and individual error terms do not contain a serial correlation. Additionally, optimal lag period selection is important, with the two appropriate rules of the Akaike Information Criterion (AIC) and Schwarz Criterion and the Bayesian information criterion (SBC) rules. As per Koehler and Murphree (1988), AIC is only a convenient construction loosely derived from maximum likelihood and has negative outcome, the SBC is strongly connected to the Bayesian theory. Therefore, this study uses the SBC rule to determine the optimum lagged term. A less calculated value, implies a better fit of the model:

\[
SBC = \ln \left( \frac{SSE}{N} \right) + \frac{k \ln(N)}{N},
\]

where \( SSE \) denotes the sum of residuals squared; \( n \) represents the number of samples, and \( k \) refers to the total number of estimated parameters.

### 3.5 Granger Causality Test

The Granger causality test (1969) determines whether a time series \( Y \) is caused by \( X \), in which the forecasts are linear and based on the information in series \( y_t \) and \( x_t \). This test also examines leading or lagging relationships among variables. For a stationary time series, the test is performed using the level value of two variables. For a non-stationary time series, the test is performed using first (or
higher) order difference(s). The number of the lag lengths is generally determined using an information criterion (i.e., SBC). Clearly, the Granger causality test handles pairs of variables, possibly yielding erroneous results when the true relationship involves more than two variables. A similar test involving more variables is applicable with VAR.

If no long-term equilibrium (co-integration) relationship exists between either X or Y, research on short-term interaction is required. This study applies the Granger causality test based on the following bivariate VAR model:

\[
X_t = m_1 + \sum_{i=1}^{p} \alpha_i X_{t-i} + \sum_{i=1}^{p} \beta_i Y_{t-i} + \varepsilon_{Xt}, \quad (7)
\]

\[
Y_t = m_2 + \sum_{i=1}^{p} \gamma_i X_{t-i} + \sum_{i=1}^{p} \delta_i Y_{t-i} + \varepsilon_{Yt}, \quad (8)
\]

where \( m_1 \) and \( m_2 \) are intercepts for \( X_t \) and \( Y_t \); \( \alpha_i \) and \( \beta_i \) denote the coefficients of the lagged terms of \( X_t \) and \( Y_t \) for \( X_t \); \( \gamma_i \) and \( \delta_i \) represent the white noises of \( X_t \) and for \( Y_t \). Moreover, \( \varepsilon_{Xt} \) and \( \varepsilon_{Yt} \) are assumed to be serially uncorrelated with a zero mean and finite covariance matrix. By using the F-test, we thus hypothesize the following:

\[
H_0 : \beta_1 = \beta_2 = \beta_3 \ldots = \beta_p = 0; \quad (9)
\]

\[
H_0' : \gamma_1 = \gamma_2 = \gamma_3 \ldots = \gamma_p = 0. \quad (10)
\]

Four conditions exist for the causal correlations between \( X_t \) and \( Y_t \):

(1) Both hypotheses are rejected, implying that \( X_t \) and \( Y_t \) have bilateral mutual feedback relations;

(2) \( H_0 \) rather than \( H_0' \) is rejected, implying that \( Y_t \) can forecast \( X_t \), but not vice versa.

(3) \( H_0' \) rather than \( H_0 \) is rejected, demonstrating that \( X_t \) can forecast \( Y_t \), but not vice versa.

(4) Neither hypotheses are rejected, representing that \( X_t \) and \( Y_t \) are mutually independent. That means \( X_t \) and \( Y_t \) are not causally related.

### 3.6 Impulse Response Function

An impulse response (IR) refers to the reaction of any dynamic system in response to an external change involving an endogenous variable. IR describes how parameters react to previous shocks in other parameters. The IR function describes the reaction of the system as a function of time. After the VAR (p) model is derived, the IR function is

\[
Z_t = \mu + \sum_{i=1}^{p} A_i Z_{t-i} + \varepsilon_t. \quad (11)
\]

According to Keating (1996), Cholesky decompositions can identify the set of a partially recursive structural model. Equation (11) can be transformed through the Wold decomposition Theorem to vector moving average representation.
(MAR) form as follows:
\[
Z_t - \sum_{i=1}^{p} A_i Z_{t-i} = \mu + \varepsilon_t,
\]
then
\[
(1 - A_1 L^1 - A_2 L^2 - \cdots - A_p L^p)Z_t = \mu + \varepsilon_t,
\]
then
\[
Z_t = \frac{\mu}{(1 - A_1 L - A_2 L^2 - \cdots - A_p L^p)} + \frac{\varepsilon_t}{(1 - A_1 L^1 - A_2 L^2 - \cdots - A_p L^P)},
\]
Hence,
\[
Z_t = \alpha + \sum_{i=1}^{\infty} C_i \varepsilon_{t-i},
\]
(12)
where \( \alpha \) is a constant vector of \((n \times 1)\); \( C \) denotes the matrix of \((n \times n)\), \( C_0 = I \) (identity matrix); \( L \) represents the lagged factor.
Equation (12) postulates that each parameter may be affected by the standard error shock of the current term and the lagged terms. While either orthogonalizing the disturbance or preventing the elements of \( \varepsilon_t \) from correlation, Cholesky decomposition takes the squared root of a positive-definite matrix. Furthermore, Cholesky decomposition decomposes a positive-definite matrix into the product of a lower triangular matrix and its conjugate transposition. Keating (1996) derived necessary and sufficient conditions for the MAR from a Cholesky decomposition to recover structural impulse responses to shocks from the particular block of recursively ordered structural equations.

The lower triangular matrix, \( V \), (i.e., \( V V' = I \)) is incorporated in the Cholesky decomposition as follows:
\[
Z_t = \alpha + \sum_{i=1}^{\infty} (C_i \times V) \times (V' \times \varepsilon_{t-i}).
\]
(13)
If \( D_i = C_i \times V \) and \( \xi_{t-i} = V' \times \varepsilon_{t-i} \),
then
\[
Z_t = \alpha + \sum_{i=1}^{\infty} D_i \xi_{t-i},
\]
(14)
where \( \xi_{t-i} \) denotes a series of random shocks which are irrelevant to the current terms. Based on the moving average equation of VAR in Eqn. (14), each parameter can be rewritten as the function of random shock items. The extent to which the size of the change in the random shock item of a specific parameter impacts other parameters can be observed. Moreover, the reaction of the shock, persistent or volatile, positive or negative impact and the extent of the reactive speed can also be observed as well.

3.7 Variance Decomposition

Although similar to the impulse response analysis, variance decomposition demonstrates the extent relative and the nature importance to which the variance of a particular shock variable can be accounted for by a shock in another variable.
Equation (14) can be rewritten as
\[ Z_t - E_{t-s} Z_t = D_0 \xi_t + D_1 \xi_{t-1} + \ldots + D_s \xi_{t-s+1}, \]  
where \( E_{t-s} Z_t \) denotes the possible forecast error of the \( t-s \)-th term when forecasting the \( t \)-th term. The variance matrix of the \( t-s \)-th term forecast error can be observed as
\[ \mathbb{E}(Z_t - E_{t-s} Z_t) (Z_t - E_{t-s} Z_t)' = D_0 \mathbb{E}(\xi_t \xi_t') D_0' + D_1 \mathbb{E}(\xi_{t-1} \xi_{t-1}') D_1' + \ldots + D_s \mathbb{E}(\xi_{t-s+1} \xi_{t-s+1}') D_s'. \]  
Equation (16) indicates that the variance of each variable can be expressed as the sum of all variables, which can be used to evaluate the extent to which the explanatory power of a specific variable contributes to itself and to other variables.

### 3.8 Model Selection

This study also examines the relationship among oil price, EUA spot price and three European stock indices by using the VAR model, first-order difference VAR model and VECM model. The models are described briefly as follows:

A. VAR model: If all the parameters belong to stationary time series, the models are listed below:

1. **OIL, EUA and FT 100:**
   \[ \text{LOIL}_t = \theta_1 + \sum_{i=1}^{p} A_{i1} \text{LOIL}_{t-i} + \sum_{i=1}^{p} B_{i1} \text{LEUA}_{t-i} + \sum_{i=1}^{p} C_{i1} \text{LUK}_{t-i} + \epsilon_{1t}, \]  
2. **OIL, EUA and DAX:**
   \[ \text{LOIL}_t = \theta_2 + \sum_{i=1}^{p} A_{i2} \text{LOIL}_{t-i} + \sum_{i=1}^{p} B_{i2} \text{LEUA}_{t-i} + \sum_{i=1}^{p} C_{i2} \text{LDAX}_{t-i} + \epsilon_{2t}, \]  
3. **OIL, EUA and CAC:**
   \[ \text{LOIL}_t = \theta_3 + \sum_{i=1}^{p} A_{i3} \text{LOIL}_{t-i} + \sum_{i=1}^{p} B_{i3} \text{LEUA}_{t-i} + \sum_{i=1}^{p} C_{i3} \text{LCAC}_{t-i} + \epsilon_{3t}. \]  

B. First-order difference VAR: For a non-stationary parameter lacking co-integration with other parameters, then a first-order difference method is used as follows:

1. **OIL, EUA and FT 100:**
   \[ \Delta \text{LOIL}_t = \theta_1 + \sum_{i=1}^{p} A_{i1} \Delta \text{LOIL}_{t-i} + \sum_{i=1}^{p} B_{i1} \Delta \text{LEUA}_{t-i} + \sum_{i=1}^{p} C_{i1} \Delta \text{LUK}_{t-i} + \epsilon_{1t}, \]  
2. **OIL, EUA and DAX:**
   \[ \Delta \text{LOIL}_t = \theta_2 + \sum_{i=1}^{p} A_{i2} \Delta \text{LOIL}_{t-i} + \sum_{i=1}^{p} B_{i2} \Delta \text{LEUA}_{t-i} + \sum_{i=1}^{p} C_{i2} \Delta \text{LDAX}_{t-i} + \epsilon_{2t}, \]  
3. **OIL, EUA and CAC:**
   \[ \Delta \text{LOIL}_t = \theta_3 + \sum_{i=1}^{p} A_{i3} \Delta \text{LOIL}_{t-i} + \sum_{i=1}^{p} B_{i3} \Delta \text{LEUA}_{t-i} + \sum_{i=1}^{p} C_{i3} \Delta \text{LCAC}_{t-i} + \epsilon_{3t}. \]
\[ \Delta \text{OIL}_t = \mu_4 + \sum_{i=1}^{p} A_{4i} \Delta \text{OIL}_{t-i} + \sum_{i=1}^{p} B_{4i} \Delta \text{EUA}_t + \sum_{i=1}^{p} C_{4i} \Delta \text{DAX}_t + \varepsilon_{4t}, \]  
(29)

\[ \Delta \text{EUA}_t = \mu_5 + \sum_{i=1}^{p} A_{5i} \Delta \text{OIL}_{t-i} + \sum_{i=1}^{p} B_{5i} \Delta \text{EUA}_t + \sum_{i=1}^{p} C_{5i} \Delta \text{DAX}_t + \varepsilon_{5t}, \]  
(30)

\[ \Delta \text{DAX}_t = \mu_6 + \sum_{i=1}^{p} A_{6i} \Delta \text{OIL}_{t-i} + \sum_{i=1}^{p} B_{6i} \Delta \text{EUA}_t + \sum_{i=1}^{p} C_{6i} \Delta \text{DAX}_t + \varepsilon_{6t}, \]  
(31)

3. OIL, EUA and CAC:

\[ \Delta \text{OIL}_t = \mu_7 + \sum_{i=1}^{p} A_{7i} \Delta \text{OIL}_{t-i} + \sum_{i=1}^{p} B_{7i} \Delta \text{EUA}_t + \sum_{i=1}^{p} C_{7i} \Delta \text{CAC}_t + \varepsilon_{7t}, \]  
(32)

\[ \Delta \text{EUA}_t = \mu_8 + \sum_{i=1}^{p} A_{8i} \Delta \text{OIL}_{t-i} + \sum_{i=1}^{p} B_{8i} \Delta \text{EUA}_t + \sum_{i=1}^{p} C_{8i} \Delta \text{CAC}_t + \varepsilon_{8t}, \]  
(33)

\[ \Delta \text{CAC}_t = \mu_9 + \sum_{i=1}^{p} A_{9i} \Delta \text{OIL}_{t-i} + \sum_{i=1}^{p} B_{9i} \Delta \text{EUA}_t + \sum_{i=1}^{p} C_{9i} \Delta \text{CAC}_t + \varepsilon_{9t}, \]  
(34)

C. VECM: For a non-stationary parameter having co-integration with other parameters, then the long-term equilibrium relationship is examined using a VECM as follows:

1. OIL, EUA and FT100:

\[ \Delta \text{OIL}_t = \mu_1 + \sum_{i=1}^{p} A_{1i} \Delta \text{OIL}_{t-i} + \sum_{i=1}^{p} B_{1i} \Delta \text{EUA}_t + \sum_{i=1}^{p} C_{1i} \Delta \text{UK}_t + \lambda_1 Z_{1t} + \varepsilon_{1t}, \]  
(35)

\[ \Delta \text{EUA}_t = \mu_2 + \sum_{i=1}^{p} A_{2i} \Delta \text{OIL}_{t-i} + \sum_{i=1}^{p} B_{2i} \Delta \text{EUA}_t + \sum_{i=1}^{p} C_{2i} \Delta \text{UK}_t + \lambda_2 Z_{2t} + \varepsilon_{2t}, \]  
(36)

\[ \Delta \text{UK}_t = \mu_3 + \sum_{i=1}^{p} A_{3i} \Delta \text{OIL}_{t-i} + \sum_{i=1}^{p} B_{3i} \Delta \text{EUA}_t + \sum_{i=1}^{p} C_{3i} \Delta \text{UK}_t + \lambda_3 Z_{3t} + \varepsilon_{3t}, \]  
(37)

2. OIL, EUA and DAX:

\[ \Delta \text{OIL}_t = \mu_4 + \sum_{i=1}^{p} A_{4i} \Delta \text{OIL}_{t-i} + \sum_{i=1}^{p} B_{4i} \Delta \text{EUA}_t + \sum_{i=1}^{p} C_{4i} \Delta \text{DAX}_t + \lambda_4 Z_{4t} + \varepsilon_{4t}, \]  
(38)

\[ \Delta \text{EUA}_t = \mu_5 + \sum_{i=1}^{p} A_{5i} \Delta \text{OIL}_{t-i} + \sum_{i=1}^{p} B_{5i} \Delta \text{EUA}_t + \sum_{i=1}^{p} C_{5i} \Delta \text{DAX}_t + \lambda_5 Z_{5t} + \varepsilon_{5t}, \]  
(39)

\[ \Delta \text{DAX}_t = \mu_6 + \sum_{i=1}^{p} A_{6i} \Delta \text{OIL}_{t-i} + \sum_{i=1}^{p} B_{6i} \Delta \text{EUA}_t + \sum_{i=1}^{p} C_{6i} \Delta \text{DAX}_t + \lambda_6 Z_{6t} + \varepsilon_{6t}, \]  
(40)

3. OIL, EUA and CAC:

\[ \Delta \text{OIL}_t = \mu_7 + \sum_{i=1}^{p} A_{7i} \Delta \text{OIL}_{t-i} + \sum_{i=1}^{p} B_{7i} \Delta \text{EUA}_t + \sum_{i=1}^{p} C_{7i} \Delta \text{CAC}_t + \lambda_7 Z_{7t} + \varepsilon_{7t}, \]  
(41)

\[ \Delta \text{EUA}_t = \mu_8 + \sum_{i=1}^{p} A_{8i} \Delta \text{OIL}_{t-i} + \sum_{i=1}^{p} B_{8i} \Delta \text{EUA}_t + \sum_{i=1}^{p} C_{8i} \Delta \text{CAC}_t + \lambda_8 Z_{8t} + \varepsilon_{8t}, \]  
(42)

\[ \Delta \text{CAC}_t = \mu_9 + \sum_{i=1}^{p} A_{9i} \Delta \text{OIL}_{t-i} + \sum_{i=1}^{p} B_{9i} \Delta \text{EUA}_t + \sum_{i=1}^{p} C_{9i} \Delta \text{CAC}_t + \lambda_9 Z_{9t} + \varepsilon_{9t}, \]  
(43)

4. The Findings

This study first summarizes the descriptive statistics of the Brent oil (OIL) spot price, Europe Union Allowance (EUA) spot price, FTSE-100 stock index (FT100), DAX stock index (DAX) and CAC 40 stock index (CAC).

The sample period lasts from March 9, 2005 to December 31, 2012. 1,855 pieces of daily data are available after deleting any missing data for any variable.

The sample period is further divided into three sub-periods to examine the relationship between EUA, OIL and three indices during different periods: March 9, 2005 to December 31, 2007 (containing 670 pieces of daily data), January 1, 2008 to December 31, 2010 (containing 706 pieces of daily data), and January 1, 2011 to December 31, 3012 (containing 479 pieces of daily...
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data). Figure 1 displays the trend of all parameters for the full sample period.

Table 1. Summary Statistics of the Full Sample Period and First Sub-period

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<tr>
<th></th>
<th>Full Sample Period</th>
<th>First Sub-period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OIL</td>
<td>EUA</td>
</tr>
<tr>
<td>Mean</td>
<td>61.5</td>
<td>12.8</td>
</tr>
<tr>
<td>Median</td>
<td>58.0</td>
<td>13.7</td>
</tr>
<tr>
<td>Max</td>
<td>96.8</td>
<td>30.0</td>
</tr>
<tr>
<td>Minimum</td>
<td>24.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>16.5</td>
<td>7.50</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.3</td>
<td>-0.0</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>2.0</td>
<td>2.4</td>
</tr>
<tr>
<td>J-B value</td>
<td>206.9</td>
<td>53.3</td>
</tr>
<tr>
<td>p-value</td>
<td>0.00***</td>
<td>0.00**</td>
</tr>
<tr>
<td>#of Obs.</td>
<td>1855</td>
<td>1855</td>
</tr>
</tbody>
</table>

Note: ***denotes 1% significance level.

Tables 1 and 2 indicate that the coefficients of the skewness of OIL and CAC are greater than zero for the full sample period and for the second and third sub-periods. This finding suggests that these three parameters skewed to right, and the other parameters skewed to left, except EUA skewed to right during the third sub-period. According to these tables, the coefficient of kurtosis of FT100 for the full sample period and that of the EUA for the second sub-period are leptokurtic (Ku > 3), while all the other parameters are platykurtic (i.e. Ku < 3). Table 1 also reveals that the p-values of J-B for all parameters for the full sample period are less than 1%, implying that all parameters do not follow a normal distribution for the full sample period.
Table 2. Summary Statistics of the Second and Third Sub-periods

<table>
<thead>
<tr>
<th></th>
<th>Second Sub-period</th>
<th>Third Sub-period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OIL</td>
<td>EUA</td>
</tr>
<tr>
<td>Mean</td>
<td>56.8</td>
<td>15.1</td>
</tr>
<tr>
<td>Median</td>
<td>58.5</td>
<td>14.5</td>
</tr>
<tr>
<td>Maximum</td>
<td>91.9</td>
<td>28.8</td>
</tr>
<tr>
<td>Minimum</td>
<td>24.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>13.9</td>
<td>6.1</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.1</td>
<td>-0.3</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>2.7</td>
<td>4.1</td>
</tr>
<tr>
<td>J-B value</td>
<td>5.1</td>
<td>48.9</td>
</tr>
<tr>
<td>p-value</td>
<td>0.08*</td>
<td>0.00***</td>
</tr>
<tr>
<td>#of Obs.</td>
<td>706</td>
<td>706</td>
</tr>
</tbody>
</table>

Note: ***denotes 1% significance level, *represents 10% significance level.

Figure 1. Original Time Series Charts for Each Parameter

(a) OIL

(b) EUA

(c) FT-100

(d) DAX
Resources: EIA US, EEX and TEJ

4.1 ADF Tests Results

This study then performs the ADF for the full sample period and three sub-periods. Table 3 indicates that all original data during all periods are non-stationary, capable of heavily influencing the behavior and properties of this time series. The first order difference is then taken and all data under the “first-order difference” column of Table 3 become stationary. This finding implies the feasibility of examining the long-term equilibrium relationship for all parameters by using the co-integration test of Johansen (1988).

<table>
<thead>
<tr>
<th>Tests</th>
<th>Full Sample Period</th>
<th>First Sub-period</th>
<th>Second Sub-period</th>
<th>Third Sub-period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original</td>
<td>First-Order</td>
<td>Original</td>
<td>First-Order</td>
</tr>
<tr>
<td></td>
<td>ADF</td>
<td>Difference</td>
<td>ADF</td>
<td>Difference</td>
</tr>
<tr>
<td>OIL</td>
<td>0.40</td>
<td>-45.56***</td>
<td>0.85</td>
<td>-27.04***</td>
</tr>
<tr>
<td>EUA</td>
<td>-1.18</td>
<td>-40.09***</td>
<td>-0.87</td>
<td>-20.01***</td>
</tr>
<tr>
<td>FT100</td>
<td>0.05</td>
<td>-45.29***</td>
<td>0.92</td>
<td>-28.50***</td>
</tr>
<tr>
<td>DAX</td>
<td>0.53</td>
<td>-42.84***</td>
<td>2.25</td>
<td>-26.06***</td>
</tr>
<tr>
<td>CAC</td>
<td>-0.46</td>
<td>-45.72***</td>
<td>1.00</td>
<td>-27.76***</td>
</tr>
</tbody>
</table>

Note: *** denotes 1% significance level.
4.2 Co-integration Test Results

Table 4 reveals that, during the full sample period, the first and third sub-periods, the trace test rejects the null hypothesis that variables lack eigenvalues below the 5% critical value threshold. These findings suggest that OIL and EUA lack a long-term equilibrium relationship with three European stock indices for these periods, explaining the use of VAR analysis in this study. However, empirical findings also indicate that OIL and EUA have a co-integration relationship with DAX during the second sub-period, implying that OIL and EUA have a long-term equilibrium relationship with DAX. Hence, during the second sub-period, the VAR analysis is used for FT100 and CAC; while the VECM analysis is used for DAX.

Table 4. Trace Test: OIL and EUA vs. Three Stock Indices ($\lambda_{tr}$)

<table>
<thead>
<tr>
<th>Null Hypothesis</th>
<th>5% critical value</th>
<th>Full Sample Period</th>
<th>First Sub-period</th>
<th>Second Sub-period</th>
<th>Third Sub-period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>FT100</td>
<td>DAX</td>
<td>CAC</td>
<td>FT100</td>
</tr>
<tr>
<td>$r = 0$</td>
<td>24.28</td>
<td>11.01</td>
<td>10.16</td>
<td>8.00</td>
<td>9.20</td>
</tr>
<tr>
<td>$0 &lt; r \leq 1$</td>
<td>12.32</td>
<td>4.41</td>
<td>4.18</td>
<td>2.82</td>
<td>2.14</td>
</tr>
<tr>
<td>$1 &lt; r \leq 2$</td>
<td>4.13</td>
<td>0.10</td>
<td>0.24</td>
<td>0.40</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Note: $^*$ demonstrates 5% significance level.

4.3 Vector Error Correction Model Results

According to the Johansen’s co-integration test, the column “second sub-period” of Tables 4 reveals that OIL and EUA have a co-integration relationship with DAX during the second sub-period. A VECM test is conducted to examine the adjustment speed. Table 5 shows that the optimum lagged period for DAX is 1. Table 6 indicates that the error correction significantly and negatively affects OIL in the German stock market during the second sub-period. This finding suggests that oil price can be easily adjusted to the long-term equilibrium in DAX during the second sub-period. However, according to the second column of Table 6, the error correction significantly and positively affects EUA for DAX during the second sub-period. This finding suggests the difficulty of adjusting the EUA spot price to long-term equilibrium in the German stock market during the second sub-period.
Table 5. The Lagged Period of Oil and EUA vs. DAX for the Second Sub-period

<table>
<thead>
<tr>
<th>Lagged Period</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIC(DAX)</td>
<td>18.1712</td>
<td>18.1340*</td>
<td>18.1930</td>
<td>18.2619</td>
<td>18.3349</td>
</tr>
</tbody>
</table>

Note: * denotes the optimum lagged term based on SIC rule.

Table 6. The Adjustment Speed of DAX toward OIL and EUA for the Second Sub-period

<table>
<thead>
<tr>
<th>Adj. Speed (DAX)</th>
<th>OIL</th>
<th>EUA</th>
<th>Stock Index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-0.0387***</td>
<td>0.0164***</td>
<td>0.5762</td>
</tr>
</tbody>
</table>

Note: *** denotes 1%, significance level.

Since Tables 4 and 5 indicate that OIL and EUA lack a long-term equilibrium relationship with three stock indices during the full sample period, the first and third sub-periods, the VAR analysis should be used for these periods. Table 7 summarizes the estimated results of OIL and EUA versus three European stock indices for all periods. This study finds that OIL is affected by the 1-lagged term of OIL and EUA for the full sample period. Meanwhile, OIL remains unaffected by any factor for the first sub-period. Also, OIL is affected by the 2-lagged term of EUA, the 1- and 2-lagged terms of FT100 stock index, the 1- and 2-lagged terms of CAC stock index for the second sub-period. Meanwhile, OIL is affected by the 1-lagged term of EUA, DAX, and CAC. Our results further demonstrate that EUA is affected by the 1-lagged term of EUA itself, the 2-lagged term of FT100, the 1-lagged term of DAX and CAC indices for the full sample period. Meanwhile, EUA is affected by the 1-lagged term of EUA itself only for the first sub-period. Also, EUA is unaffected by any factor during the second sub-period. Moreover, EUA is affected by the 2-lagged term of OIL and the 1-lagged term of three European stock indices for the third sub-period.
Table 7. Summary of The Estimated VAR Results of OIL, EUA versus Three European Stock Indices for All Periods

<table>
<thead>
<tr>
<th>Period</th>
<th>Variable</th>
<th>VAR Significant Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Sample Period</td>
<td>OIL</td>
<td>OIL(-1), and EUA(-1)</td>
</tr>
<tr>
<td></td>
<td>EUA</td>
<td>EUA(-1), FT100(-2), DAX(-1), and CAC(-1)</td>
</tr>
<tr>
<td>First Sub-Period</td>
<td>OIL</td>
<td>unaffected by any factor</td>
</tr>
<tr>
<td></td>
<td>EUA</td>
<td>EUA(-1)</td>
</tr>
<tr>
<td>Second Sub-Period</td>
<td>OIL</td>
<td>EUA(-2), FT100(-1), FT100(-2), CAC(-1) and CAC(-2)</td>
</tr>
<tr>
<td></td>
<td>EUA</td>
<td>unaffected by any factor</td>
</tr>
<tr>
<td>Third Sub-Period</td>
<td>OIL</td>
<td>EUA(-1), DAX(-1), and CAC(-1)</td>
</tr>
<tr>
<td></td>
<td>EUA</td>
<td>OIL(-2), FT100(-1), DAX(-1), and CAC(-1)</td>
</tr>
</tbody>
</table>

4.4 Granger Causality Test Results

Table 8 indicates that, for the full sample period, the second and third sub-periods, EUA unilaterally affects OIL. Meanwhile, three stock indices unilaterally affect EUA below the 5% critical value threshold because all these three European countries are highly industrialized and their economic conditions affect the demand of CO₂ emissions and the EUA spot price increases.

However, as for the first sub-period, EUA lacks a causal relationship with OIL or the three stock indices. This may be owing to that this sub-period is in the first stage of EU ETS, and the EUA market is a new commodity market. All of the participants are new comers as well. Additionally, the European Commission announced that the quota from the first stage can not be transferred to the second stage in April, 2006. This announcement also discouraged the participants. Empirical findings also indicate that OIL affects FT100 and CAC during the first stage. Exactly why DAX is independent of OIL may be owing to that Germany has launched its efforts to develop renewable energy sources in 2004 until now. During the second sub-period, our results demonstrate that EUA and OIL have a mutually causal relationship, and OIL is affected by three European stock indices. However, EUA lacks a causal relationship with these three stock indices. This may be owing to that various enterprises bankrupted during this subprime loan crisis period. Correspondingly, investors withdrew from the stock markets, and various economic activities diminished the demand for EUA. As for the third sub-period, both EUA and three European stock indices unilaterally affect OIL. Moreover, three European stock indices also unilaterally affect EUA and OIL, possibly owing to that, during the European
debt crisis, the investors traded stocks more frequently than they did during the normal period, causing the stock indices lead the EUA and OIL.

### Table 8. Causality among OIL, EUA and Three European Stock Indices for Various Periods

<table>
<thead>
<tr>
<th></th>
<th>Full Sample Period</th>
<th>First Sub-period</th>
<th>Second Sub-period</th>
<th>Third Sub-period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OIL</td>
<td>EUA</td>
<td>FT100</td>
<td>OIL</td>
</tr>
<tr>
<td>OIL</td>
<td>—</td>
<td>1.48</td>
<td>3.47**</td>
<td>—</td>
</tr>
<tr>
<td>EUA</td>
<td>11.93***</td>
<td>—</td>
<td>0.90</td>
<td>0.03</td>
</tr>
<tr>
<td>FT100</td>
<td>189.21***</td>
<td>2.43*</td>
<td>—</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>OIL</td>
<td>EUA</td>
<td>DAX</td>
<td>OIL</td>
</tr>
<tr>
<td>OIL</td>
<td>—</td>
<td>1.48</td>
<td>2.21</td>
<td>—</td>
</tr>
<tr>
<td>EUA</td>
<td>11.93***</td>
<td>—</td>
<td>1.06</td>
<td>0.03</td>
</tr>
<tr>
<td>DAX</td>
<td>174.21***</td>
<td>1.96*</td>
<td>—</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>OIL</td>
<td>EUA</td>
<td>CAC</td>
<td>OIL</td>
</tr>
<tr>
<td>OIL</td>
<td>—</td>
<td>1.48</td>
<td>4.79**</td>
<td>—</td>
</tr>
<tr>
<td>EUA</td>
<td>11.93***</td>
<td>—</td>
<td>0.86</td>
<td>0.02</td>
</tr>
<tr>
<td>CAC</td>
<td>140.01***</td>
<td>2.03*</td>
<td>—</td>
<td>0.41</td>
</tr>
</tbody>
</table>

Note: *** denotes 1% significance level, ** represents 5% significance level, and * demonstrates 10% significance level, respectively.

### 4.5 Impulse Response Function Results

The impulse response function examines how an external change affects an endogenous variable and other variables. Figures 2 to 9 indicate that, for the full sample period and all three sub-periods, OIL and EUA are most positively and significantly affected by OIL and EUA shocks, respectively, at the first term; they then converge rapidly for short periods. Our results further demonstrate that, either OIL or EUA impacts the three European stock indices for all periods. However, the extent to which OIL impacts EUA appears to yield mixed results for various periods. Meanwhile, OIL is positively and significantly affected by EUA at the first term for the full sample period, as well as the second and third sub-periods. However, EUA insignificantly influences OIL during the first sub-period.
Figure 2. Impulse Response of Six Parameters from Oil Shock for the Full Sample Period

(a) Response of OIL from OIL shock

(b) Response of EUA from OIL shock

(c) Response of FT100 from OIL shock

(d) Response of DAX from OIL shock

(e) Response of CAC from OIL shock

Figure 3. Impulse Response of Six Parameters from EUA for the Full Sample Period

(a) Response of OIL from EUA shock

(b) Response of EUA from EUA shock

(c) Response of FT100 from EUA shock

(d) Response of DAX from EUA shock

(e) Response of CAC from EUA shock
Figure 4. Impulse Response of Six Parameters from OIL Shock for the First Sub-period  
(a) Response of OIL from OIL shock  
(b) Response of EUA from OIL shock  
(c) Response of FT100 from OIL shock  
(d) Response of DAX from OIL shock  
(e) Response of CAC from OIL shock

Figure 5. Impulse Response of Six Parameters from EUA for the First Sub-period  
(a) Response of OIL from EUA shock  
(b) Response of EUA itself from EUA shock  
(c) Response of FT100 from EUA shock  
(d) Response of DAX from EUA shock  
(e) Response of CAC from EUA shock
EUA shock

(d) Response of DAX from EUA shock

(e) Response of CAC from EUA shock

Figure 6. Impulse Response of Six Parameters from OIL for the Second Sub-period

(a) Response of OIL from OIL shock

(b) Response of EUA from OIL shock

(c) Response of FT100 from OIL shock

(d) Response of DAX from OIL shock

(e) Response of CAC from OIL shock
Figure 7. Impulse Response of Six Parameters from EUA for the Second Sub-period
(a) Response of OIL from EUA shock   (b) Response of EUA from EUA shock   (c) Response of FT100 from EUA shock
(d) Response of DAX from EUA shock   (e) Response of CAC from EUA shock

Figure 8. The Impact of OIL Shock on Six Parameters for the Third Sub-period
(a) Response of OIL from OIL shock   (b) Response of EUA from OIL shock   (c) Response of FT100 from OIL shock
Response of DOIL to DEUA

Response of DEUA to DEUA

Response of DUK to DEUA

Response of DDAX to DEUA

Response of DCAC to DEUA

Response of DOIL to DOIL

Response of DEUA to DOIL

Figure 9. The Impact of EUA Shock on Six Parameters for the Third Sub-period

(a) Response of OIL from EUA shock  (b) Response of EUA itself from EUA shock  (c) Response of FT100 from EUA shock

(d) Response of DAX from EUA shock  (e) Response of CAC from EUA shock
4.6 Variance decomposition results

This study summarizes the variance decomposits results at Table 9:

(1) As for the OIL variance decomposition analysis, the only explanatory power on the shocks to OIL at the first term arises from OIL itself for all periods. However, that explanatory power arising from OIL itself decrease significantly from the first term to the second term, then remains the same from the fourth or the fifth term for all periods except for the first sub-period. The second most significantly explanatory power, for the full sample period, the second and third sub-periods, is owing to that arises from FT100 from the second term, ultimately decreasing and remaining the same since the fourth or the fifth term.

(2) As for the EUA variance decomposition, EUA itself is most significantly influenced by the shocks of EUA for all the periods, with all exceeding 94.9%.
Table 9 Summary of Variance Decomposition Results for Multiple Periods

<table>
<thead>
<tr>
<th></th>
<th>Variance Decomposition Results of Oil</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full Sample Period</td>
<td>First Sub-period</td>
</tr>
<tr>
<td>Terms</td>
<td>OIL EUA FT100 DAX CAC</td>
<td>OIL EUA FT100 DAX CAC</td>
</tr>
<tr>
<td>1</td>
<td>100 0.0 0.0 0.0 0.0</td>
<td>100 0.0 0.0 0.0 0.0</td>
</tr>
<tr>
<td>2</td>
<td>89.6 0.6 8.8 0.3 0.8</td>
<td>99.0 0.0 0.0 0.3 0.1</td>
</tr>
<tr>
<td>3</td>
<td>89.2 0.6 8.9 0.5 0.8</td>
<td>98.2 0.0 0.1 0.3 0.5</td>
</tr>
<tr>
<td>4</td>
<td>89.2 0.6 8.9 0.5 0.8</td>
<td>98.2 0.0 0.1 0.4 0.5</td>
</tr>
<tr>
<td>5</td>
<td>89.2 0.6 8.9 0.5 0.8</td>
<td>98.2 0.0 0.1 0.4 0.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Variance Decomposition Results of EUA</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full Sample Period</td>
<td>First Sub-period</td>
</tr>
<tr>
<td>Terms</td>
<td>OIL EUA FT100 DAX CAC</td>
<td>OIL EUA FT100 DAX CAC</td>
</tr>
<tr>
<td>1</td>
<td>0.0 100 0.0 0.0 0.0</td>
<td>3.9 96.1 0.0 0.0 0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.0 99.8 0.0 0.0 0.0</td>
<td>4.3 95.1 0.0 0.2 0.2</td>
</tr>
<tr>
<td>3</td>
<td>0.0 99.2 0.2 0.1 0.0</td>
<td>4.3 95.0 0.0 0.2 0.3</td>
</tr>
<tr>
<td>4</td>
<td>0.1 99.2 0.2 0.1 0.0</td>
<td>4.3 95.0 0.0 0.2 0.3</td>
</tr>
<tr>
<td>5</td>
<td>0.1 99.2 0.2 0.1 0.0</td>
<td>4.3 95.0 0.0 0.2 0.3</td>
</tr>
</tbody>
</table>
5. Summary and Conclusions

By using time series models, this study examines the relationship among the Brent oil price, EUA spot price and three European stock indices from March 9, 2005 to Dec. 31, 2012. The sample period is divided into three sub-periods, followed by a comparison of the empirical results over three sub-periods. Based on the results of this study, we conclude the following:

1. Co-integration test results indicate that Brent oil price, EUA spot price and three European stock indices do not have long-term equilibrium relationships for the full sample period, the first sub-period, and the third sub-period. However, empirical findings reveal that Brent oil and EUA spot prices, and DAX index have a co-integration equilibrium relationship during the second sub-period;

2. Following a VECM test, the error correction significantly and negatively affects the Brent oil price in the German stock market during the second sub-period, implying that the Brent oil price can be adjusted to the long-term equilibrium in the German market. However, the EUA spot price has difficulty in adjusting to long-term equilibrium in the German stock market during the second sub-period;

3. Empirical results based on the VAR test indicates that the Brent oil price is significantly affected by itself, and EUA spot price. Meanwhile, EUA spot price is influenced by itself and three European stock indices for the full sample period. As for the first sub-period, The Brent oil price remains unaffected by any factor. Meanwhile, EUA spot price is significantly affected by itself. For the second sub-period, the Brent oil price is affected by the EUA spot price and the British and French stock markets. EUA spot price remains unaffected by any factor. For the third sub-period, both the Brent oil and EUA spot prices are affected by three European stock indices. EUA spot price is also affected by the Brent oil price, but not vice versa;

4. Based on the Granger causality test, EUA spot price unilaterally affects oil price. Meanwhile, three European stock indices unilaterally influence the Brent oil and the Brent EUA spot prices below the 5% critical value threshold for full sample period and the second and third sub-periods. However, the EUA spot price lacks a causal relationship with oil price and three stock indices during the first sub-period;

5. Based on the impulse response function, the oil and EUA spot prices are most significantly affected by oil and EUA spot prices shock themselves,
respectively. Additionally, they converge rapidly during short periods. The three European stock indices are significantly influenced by the Brent oil and EUA spot prices. Also, these indices converge rapidly during short periods for the full sample period, and all three sub-periods after they are affected by oil and EUA spot price shocks;

6. Variance decomposition analysis results indicate that the most significantly explanatory power on the Brent oil price arises from itself in the first term for all periods. The second most significantly explanatory ability with respect to oil price for the full sample period, the second and third sub-periods since the second term arises from British stock index. Our results further demonstrate that the most significantly explanatory power on EUA spot price arises from the EUA spot price itself for all periods, with all exceeding 94.90%.

In summary, this study concludes that the Brent oil price is affected by EUA spot price for the full sample period, the second sub-period and the third sub-period. EUA spot price is unaffected by and other factor for the full sample period and the third sub-period. Meanwhile, the Brent oil price is unaffected by any factor for the first sub-period.

End Notes

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References


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