Dynamic Simulation Analysis on EUA and CER Futures Prices at Two Phases of European Union Emission Trading Scheme

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Abstract
Based on data from European Union Emission Trading Scheme (EU ETS) 2nd phase, 3rd phase, and outlier-free 3rd phase, we used Johansen test, vector error correction, pulse response function and variance decomposition to empirically compare the long-term equilibrium relationships as well as interactions of futures prices of two major EU ETS commodities: European Union Allowance (EUA) and Certified Emission Reduction (CER). We find long-term stable positive equilibrium relationship for EUA and CER futures prices at the 2nd phase, but at the 3rd phase, co-integration of full-sample data disappears, while a positive equilibrium relationship occurs after outlier exclusion, though weaker compared with the 2nd phase. The EUA futures prices at the 3rd phase after outlier exclusion are more sensitive to market changes, but due to the complication of uncertainty factors at the 3rd phase, the correction direction of CER futures prices is changed. EUA versus CER futures prices do not show strong linkage at the 2nd phase, and the guiding role of a certain price disappears.

Keywords: European Union Emission Trading Scheme, EUA Futures, CER Futures, Dynamic Simulation Analysis.

1. INTRODUCTION
1.1. Background
The United Nations Framework Convention on Climate Change approved in United Nations Conference on Environment and Development in 1992 qualitatively provided the objectives and obligations on relief of climate changes. Then in 16 February 2005, the implementation of Kyoto Protocol signified the objective of retaining greenhouse gas emissions in the legal form for the first time in human history, which led to the appearance of global carbon finance markets and carbon trading.

The World Bank Annual Report 2014 shows that between 2004 and 2011, the trading volume and turnover in international carbon trading markets were basically maintained at large-rate increase annually, as the turnover soared to 176 billion dollars in 2011, by a rise of 11% from 2010, while the trading volume was 10.3 billion tons and the trading volume of carbon dioxide was maximized (Li, Xu and Li, 2013). The total trading volume in global carbon market was about 9 billion tons in 2014, with a total turnover of 50.02 billion euros. The total trading volume in 2014 dropped by 12% from 2013, but the total turnover rose by 25% (Zhang, 2015). In recent years, the total turnover of international carbon trading has dropped to some degree, but this does not deter the global carbon trading market from becoming mature. In particular, the major impetus behind is the European Union Emission Trading Scheme (EU ETS), which has always been dominant in the international carbon trading market. Moreover, the involvement of more and more developing countries has injected new blood into the international carbon trading markets.

1.1.1. Current Situation of EU ETS
Compared with other trading schemes, EU ETS becomes the most important and effective carbon trading scheme worldwide. EU ETS started in a multi-phase way since 2005: 1st phase (2005-2007) aimed to acquire experience in emission trading; 2nd phase (2008-2012), the same operation time as Kyoto Protocol; since 2013, every five years were defined as one phase. Since 2005, the trading volume and turnover after decentralization have increased rapidly from EU ETS, and so far, EU ETS becomes the impetus for the sustainability of European and global carbon trading markets. According to Global New Energy Development Report 2015, the total trading volume in 2014 was 8.703 billion tons, a 4.35% drop from 2013, while the total turnover was 47.505 billion Euro, a 24.56% increase from 2013.

The two major climate trading products in EU ETS are European Union Allowance (EUA) and Certified Emission Reduction (CER). The trading volumes of EUA and CER in 2013 were 8.65 and 0.709 billion tons, respectively, and the turnovers were 52.348 and 0.4 billion dollars, respectively. The total trading volume from EUA in 2014 was 8.336 billion tons, but the total turnover from EUA nearly accounted for that of the EU market, because the market trading price of offset credit was almost 0 Euro per ton of CO2 equivalent(Zhang, 2015). The decline of EUA trading volume modestly reflected the recession of enthusiasm for carbon trading in
the global market. Since EUA was developed before CER and the entities of CER are developing countries, these two major products are developing at different paces.

1.1.2. Current Situation of Carbon Trading in China

The carbon market in China was started in 2013 and developed most rapidly in 2014. According to the National 12th Five-Year Plan, the Chinese government proposed to "build a decentralized emission trading market step by step". During the construction of carbon trading markets in China, as prescribed in Kyoto Protocol, China and other developing countries are not legally responsible for greenhouse gas emission reduction. However, as the largest developing country and under the development strategy of “One Belt and One Road”, China has made progress in carbon trading through voluntary emission reduction projects. By 2014, China Beijing Environment Exchange had completed a trading volume of nearly 500000 tons of voluntary emission reduction, involving 30 projects and nearly 30000 cases of individual purchase (Li, 2013). Thus, the carbon trading market in China has entered the active period. In 2017, China will build a state-level united carbon market core exchange in Beijing.

As for construction of international carbon trading markets, according to Kyoto Protocol, Clean Development Mechanism (CDM) is the only way for China to implement greenhouse gas emission reductions and take part in international carbon trading. Since the formal execution of CDM projects since 2005 and by 1 July 2013, there were 3653 registered CDM projects, involving multiple industries. These CDM projects could be divided into two categories: (1) polluting industries that expect to reduce emission and save energy through CDM projects, such as chemical industry and power generation industry; (2) industries that would, via research & development creation, produce positive externality to the environment, such as biomass energy, afforestation and reforestation industries (Yang, Wan, Sun and Li, 2014). In summary, in the global carbon trading market of primary products, China has become the biggest supplier, indicating the Chinese CDM market is developing rapidly and increasingly mature.

1.2. Review

Kyoto Protocol took effect in 2005 and subsequently stimulated the global carbon trading markets. In particular, EU ETS is the first and most powerful carbon trading market in the world. In addition to spot trading, the carbon futures market has attracted growing attention from the research field, because it provides enterprises with risk-averse carbon futures products, and the existing research is focused on the futures products in the EU ETS.

1.2.1. Worldwide Research on Carbon Futures Markets

The vigorous development of international financial markets and carbon futures has attracted numerous researchers. Chevallier (2009) studied the relationship between carbon futures contract revenue and macroeconomic factors and analyzed the changes of carbon futures yield under macroeconomic conditions (Julien, 2009). It was found that the prices of carbon futures did not respond to macroeconomic changes immediately, but were significantly affected by the quota allocation and power demand (Julien, 2009). Byun and Cho (2013) investigated the abilities of three methods to predict carbon price fluctuation: Generalized Auto Regressive Conditional Heteroskedasticity (GARCH); hidden fluctuation rates of carbon futures prices and option prices; K nearest neighbor (Byun, Cho, 2013). Carbon option did not show any information spillover effect on carbon futures, because of too small trading volume (Byun, Cho, 2013). They also studied the effects of energy market fluctuation on the carbon futures market and found the fluctuation of carbon futures could be predicted by the crude oil, coal and power market prices (Byun, Cho, 2013). Moreover, other studies are focused on the relationship between carbon spot prices and futures prices.

Theissen (2011) used the error correction model to investigate the spot and futures prices in EU ETS and tested the discovering ability of EUA futures prices (Theissen, 2011). Compared with the spot market, the futures markets could more efficiently and sensitively absorb and transfer market signals. Namely, the prices of the EUA futures market could obviously guide the carbon quota prices in the spot markets, but the impacts due to the presence of arbitrage opportunity cannot be ignored during the price discovery process (Theissen, 2011). Using Vector Autoregressive (VAR) model, Koop and Tole (2013) studied the relationship between EUA futures/spot prices and CER spot prices and proved the presence of contemporary causality among these three variables, and found the EUA futures prices played a dominant role in promoting this causality (Koop and Tole, 2013).

1.2.2. Research in China on Carbon Futures Markets

Chinese researchers started to investigate EU carbon futures markets only in recent years. There are two main trends: (1) the linkage between carbon futures markets and other energy markets; (2) the internal development conditions and effectiveness in carbon futures markets.
Liu Jixian et al. (2013) empirically investigated the relationship about the changes between carbon futures market and energy stock market, and found the asymmetric correlation between carbon futures prices and energy share prices (Liu, Zhang and Zhang, 2013). The fluctuation of energy share prices could significantly affect the carbon futures prices, but the fluctuation of carbon futures prices does not significantly impact the energy share prices (Liu, Zhang and Zhang, 2013). Zhang Zeming and Yan Xia (2014) empirically studied the relationships of EUA futures market with power and energy source markets. They found long-term cointegration and short-term guiding relationship among the three variables; the EUA futures prices positively respond to the impact of power futures prices, and far more severely affected both energy and power futures prices compared with the interaction between the energy and power futures prices (Zhang and Yan, 2014). Zhao Jingwen (2012) further divided the energy markets and analyzed the causality of main EUA prices with coal, power, natural gas, and oil prices (Liu, Zhang and Zhang, 2013). The cointegration between carbon futures prices and various energy prices was proved (Zhao, 2012). Carbon futures prices were found in two-way causality with natural gas and power futures prices, in one-way causality with coal futures prices, but no causality with oil futures prices (Zhao, 2012).

Liu Zhuo (2010) qualitatively analyzed the effectiveness of market scale, investor structure, trading system, and information transparency in the EUA futures market, and quantitatively investigated the long-term or short-term effectiveness of EUA futures market as well as prices. It is found that the majority of contracts are efficient at long-term, but not at short-term, and the discovering ability of spot prices is stronger versus futures prices. Tian Biao (2015) analyzed specific aspects of market participators, futures contracts, risk control and market running, and pointed out China has created the basic conditions for development of emission decentralized futures markets, and recommended to learn from the experiences of futures market construction in EU ETS. Besides carbon futures markets, Chinese researchers also paid attention to the prices of carbon futures products, but they focused on single products. With VAR model and impulse response analysis, Wu Heng yu et al. (2011) study the relations between CER spot market and futures markets and the effect of price shock, and found that CER futures market has shown a certain price discovery function; Reponses of CER spot price to itself and futures prices exhibit high positive effects while responses of CER futures prices to themselves and CER spot price show low positive effects (Wu, Hu, Qin and Liu, 2011). VAR investigation and empirical analysis reveal the presence of cointegration between spot and futures prices for both EUA and CER, and also the futures prices of EUA could guide its spot prices (Hong and Chen, 2010).

A review on Chinese studies about carbon futures markets shows that the relationship between the futures prices of EUA and CER (the two major EU ETS trading products) in recent two years has been rarely studied. A detailed study on second phase data (August 7, 2009 to August 31, 2011) reveals a strong long-term balanced cointegration between the CER and EUA futures prices (Sheng, 2013). Moreover, the CER versus EUA futures prices are more responsive to market changes, and the pricing function of CER significantly affects that of EUA, showing a leverage effect (Sheng, 2013).

So far, China has brought onto agenda the establishment of carbon futures markets, while EU ETS has entered the third phase under the complex international environment. A comparative study on the achievements of main commodity futures prices between the second and third phases would help to further understand the carbon futures markets in China, and provide some inspirations for construction of effective carbon futures markets.

2. METHODS

Time series is a sequence of a statistical index ranking in chronological order. The main objective of time series observation and analysis is to use historical data to predict the upcoming trend. In early days, least square method was widely applied to study the prices of futures markets, but its use into regression of time series, which is generally non-stationary, would induce spurious regression. Vector error correction (VEC) is now the most-used algorithm to study the dynamic change relationships of futures market prices.

2.1. Data Preprocessing

However, real-life economic data generally do not conform to the requirements of econometric models and thus require preprocessing. Before VEC being used into economic data analysis, we have to test the stationeriness of time series. There are two major methods for such purpose.

2.1.1. Observation Test

By definition, a time series is considered as stationary if neither its mean nor variance shows any trend and the periodical variation is strictly eliminated. Thus, we can draw a time series plot and observe whether the values fluctuate with time around a constant at an approximate distance. If a series shows evident trend or periodicity, we preliminarily consider this time series is non-stationary.
2.1.2. Unit Root Test

The observation method only provides a rough result and is evidently non-scientific, so unit root test is needed to accurately determine the stationeriness of data. For this purpose, if a unit root exists in the test result, this series is non-stationary.

Unit root test is finished mainly via two ways: Dickey-Fuller (DF) Test and Augmented DF (ADF) Test. In fact, ADF test is expanded from the DF test along with further research. DF test assumes that a time series is generated from the first-order autoregression of white noise stochastic interference item, but admittedly, this hypothesis is not general. Thus, we used the ADF test, which is introduced below.

In the ADF test, the high-order serial correlation is controlled by adding a $\Delta y_t$ lag difference term into the right side of the DF regression equation. The test equation is:

Without constant term:

$$\Delta y_t = \gamma y_{t-1} + \varepsilon_1 \Delta y_{t-1} + \varepsilon_2 \Delta y_{t-2} + \ldots + \varepsilon_p \Delta y_{t-p+1} + \varepsilon_t \quad (1)$$

With constant term:

$$\Delta y_t = \alpha + \gamma y_{t-1} + \varepsilon_1 \Delta y_{t-1} + \varepsilon_2 \Delta y_{t-2} + \ldots + \varepsilon_p \Delta y_{t-p+1} + \varepsilon_t \quad (2)$$

With trend term:

$$\Delta y_t = \alpha + \gamma y_{t-1} + \varepsilon_1 \Delta y_{t-1} + \varepsilon_2 \Delta y_{t-2} + \ldots + \varepsilon_p \Delta y_{t-p+1} + c + \varepsilon_t \quad (3)$$

where $p$ is the lag order of $y_t$. For these three regression equations, the null hypothesis $H_0$ is: $\gamma = 0$, a unit root exists; the alternative hypothesis $H_1$: $\gamma < 0$. In the test, the equation is used from down-to-up, if the result rejects the null hypothesis, this series is stationary; test ends. Otherwise, the above two equations are used until the null hypothesis is rejected. If the null hypothesis cannot be rejected at all, this series is non-stationary.

2.2. VEC

For a VAR model containing $n$ variables, when the corresponding matrix has a rank between 0 and $n$, or namely $0 < r < n$, then there are $r$ cointegrations between these $n$ variables. Then define an $r$-dimension matrix $A$, which contains $n \times r$ linear independent cointegration vectors, marked as rank($A$)=$r$.

Then define:

$$Z_t = A' Y_t \quad (4)$$

Since rank($\Pi$) = $r$, while the rows of matrix $A'$ from Eq. (4) contain $r$ linear irrelevant rows coming from matrix $\Pi$, then all $n$ rows from matrix $\Pi$ can be written as a combination of matrix $A'$, or $\Pi = BA'$. Then we get:

$$\Phi(L)\Delta Y_t = C + BA' Y_{t-1} + \varepsilon_t = C + B Z_{t-1} + \varepsilon_t \quad (5)$$

The VEC model is expressed as follows: At long-term, the equilibrium status does exist, so we have $Z_t = A' Y_t = 0$.

At short-term, for each definite time $t$, there is a component deviating from the cointegration $A' Y_t$. Such deviation is non-equilibrium at short-term, and its increase or decrease is called the error correction.

3. COMPARISON BETWEEN EUA AND CER FUTURES PRICES AT SECOND AND THIRD PHASES

3.1. Data Selection and Processing

Because more than 80% of the global futures trading is conducted in European Climate Exchange (ECX), we selected EUA and CER futures from ECX and used as the EU emission decentralized quota markets and item markets, respectively. EU ETS aimed to divide the whole reduction period into three phases. We selected the data from second and third phases for comparison. Then we found an abnormal fluctuation range in the full-sample third phase data. Since 2014, EU ERS faced many uncertainty factors. The internal causes mainly include EU emission license, carbon quota surplus, and the cross-member conflict aggravated by insider trading. The external causes mainly include the impact of European debt crisis, and controversy towards protocol constraints from global conferences, the "half-heartedness" to energy-saving and emission reduction, which together drove the carbon market prices to drop to the freezing point. Nevertheless, by the end of 2014, many countries called for a new climate protocol to be approved on by 2015, and after the CDM working group meeting in Bonn, Germany on 23 March 2015, the prices of carbon market commodities started to rise and gradually climb up. Thus, we selected three periods of data. All data were cited from the Wind database, with the unit of Euro per ton of CO2 equivalent. The data were converted to the natural logarithm so as to eliminate the potential heteroskedasticity in the financial time series.

1. EUA and CER second phase: from 2 January 2009 to 31 December 2012, involving 1027 samples; marked as $L_{EUA\_2ND}$ and $L_{CER\_2ND}$, respectively.
2. EUA and CER third phase: from 2 January 2013 to 29 February 2016, involving 815 samples; marked as L_EUA_3RD_FULL and L_CER_3RD_FULL, respectively.

3. EUA and CER third phase after outliers being excluded: from 2 January 2013 to 17 February 2014 and from 24 March 2015 to 29 February 2016, involving 533 samples; marked as L_EUA_3RD_EXCL and L_CER_3RD_EXCL, respectively.

3.2. Empirical Process, Results and Comparative Analysis

3.2.1. ADF Unit Root Test

To test whether there is long-term cointegration between variables, we had to test the stationarity of each variable. First, Figure 1a to f show the line charts of EUA and CER futures settled prices at three periods. Direct observation shows that all line charts display trend and fluctuation, but to different degrees, so we preliminarily think the six time series are all non-stationary and require unit root test.

![Figure 1](image)

The 1-order difference series of each variable was sent to ADF unit root test, and the results are listed in Table 1. Clearly, at confidence level (CI) = 1%, 5% and 10%, the ADF values of 1-order post-difference series are all smaller than the critical value, indicating the 1-order difference series of logarithm prices of each variable are all stationery, and all confirm to 1-order integrated I(1), and thus can be used into co-integration test.
### Table 1. Stationarity test of EUA and CER time series

<table>
<thead>
<tr>
<th>Sample</th>
<th>Augmented Dickey-Fuller test statistic</th>
<th>t-Statistic</th>
<th>Prob.*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test critical values: 1% level</td>
<td>L_EUA_2ND = -30.30588</td>
<td>-3.436511</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td>L_CER_2ND = -32.6398</td>
<td>0.0000</td>
<td></td>
</tr>
<tr>
<td>5% level</td>
<td>L_EUA_3RD_FULL = -14.30778</td>
<td>-3.864149</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td>L_CER_3RD_FULL = -36.16574</td>
<td>0.0000</td>
<td></td>
</tr>
<tr>
<td>10% level</td>
<td>L_EUA_3RD_EXCL = -17.35325</td>
<td>-2.568211</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td>L_CER_3RD_EXCL = -9.702214</td>
<td>0.0000</td>
<td></td>
</tr>
</tbody>
</table>

3.2.2. Johansen Test

There are two types of cointegration test: residue-targeted EG test, and coefficient-targeted Johansen test. Here multivariable Johansen test was used. If two variables both obey the cointegration test of I(d) non-stationary series and reject the null hypothesis of being without cointegration, then there is at least one co-integration between two variables.

### Table 2. JJ cointegration test of EUA and CER commodity futures at all phases

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Eigenvalue</th>
<th>5% critical value</th>
<th>P-value</th>
<th>Trace statistic</th>
<th>5% critical value</th>
<th>P-value</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2ND phase</td>
<td>None</td>
<td>64.0710</td>
<td>14.2646</td>
<td>0.055</td>
<td>67.7344</td>
<td>15.49471</td>
<td>One cointegration</td>
</tr>
<tr>
<td>At most 1</td>
<td>3.66334</td>
<td>3.841466</td>
<td>0.055</td>
<td>3.663344</td>
<td>3.841466</td>
<td>0.055</td>
<td>6</td>
</tr>
<tr>
<td>3RD_FULL phase</td>
<td>None</td>
<td>4.36127</td>
<td>14.2646</td>
<td>0.819</td>
<td>8.271695</td>
<td>15.49471</td>
<td>No cointegration</td>
</tr>
<tr>
<td>At most 1</td>
<td>3.91042</td>
<td>3.841466</td>
<td>0.048</td>
<td>3.910422</td>
<td>3.841466</td>
<td>0.048</td>
<td>8</td>
</tr>
<tr>
<td>3RD_EXCL phase</td>
<td>None</td>
<td>14.0705</td>
<td>14.2646</td>
<td>0.053</td>
<td>16.5912</td>
<td>15.49471</td>
<td>One cointegration</td>
</tr>
<tr>
<td>At most 1</td>
<td>2.52069</td>
<td>3.841466</td>
<td>0.112</td>
<td>2.520699</td>
<td>3.841466</td>
<td>0.112</td>
<td>4</td>
</tr>
</tbody>
</table>

All three situations were tested under the hypothesis of "with intercept and without trend term". As showed in Table 2, the trace test indicates the null hypothesis is rejected at p<5% for both 2ND phase and 3RD_EXCL phase; the maximum eigenvalue test of 2ND phase also rejects at p<5%, indicating there is cointegration between EUA and CER at both 2ND phase and 3RD_EXCL phase. The trace test and maximum eigenvalue test for the 3RD_FULL phase both accept the null hypothesis at P<5%, indicating there is no cointegration between L_EUA_3RD_FULL and L_CER_3RD_FULL. Thus, the algebraic expression based on the cointegration is:

2nd phase: L_EUA_2ND = 0.751707 × L_CER_2ND
3rd_EXCL phase: L_EUA_3RD_EXCL = 0.676532 × L_CER_3RD_EXCL

It is indicated that in the long run, if the CER futures prices rise by 1% in 2ND phase and other conditions are unchanged, the EUA futures prices will rise by 0.751707%. In the 3RD_EXCL phase, if the CER futures prices rise by 1% and other conditions are unchanged, the EUA futures prices will rise by 0.676532%.

Thus, there is strong positively-correlated long-term equilibrium cointegration between EUA and CER futures prices at 2ND phase, without cointegration in the 3RD_FULL phase, but there is weaker positive changing long-term equilibrium cointegration at 3RD_EXCL phase versus 3RD_FULL phase.

3.2.3. Results of VEC Computation

Based on cointegrations, a VEC model can be built and used to further study the between-variable non-equilibrium error that deviates from long-term equilibrium relationship. According to JJ test results, there is no cointegration between L_EUA_3RD_FULL and L_CER_3RD_FULL futures prices, which does not meet the condition for subsequent analysis. Thus, only 2ND and 3RD_EXCL phases were selected for subsequent analysis. First, the lag order number is determined: the lag term in the original 2ND phase series is 3; the lag term in the VEC model is that of the original series minus 1, so the lag term in the 2ND phase VEC model is 2. Similarly, the lag term of the original series at 3RD_EXCL phase is 8, so the lag term in the VEC model is 7.
Due to limitation of space, Table 3 only shows a part of the VEC computations at 2ND phase and 3RD_EXCL phase.

**Table 3. A part of results from VEC computation**

<table>
<thead>
<tr>
<th></th>
<th>2ND phase</th>
<th>3RD_EXCL phase</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Error Correction</strong></td>
<td><strong>L_EUA_2ND</strong></td>
<td><strong>L_CER_2ND</strong></td>
</tr>
<tr>
<td>CointEq1</td>
<td>-0.002668</td>
<td>-0.00419</td>
</tr>
<tr>
<td>Determinant resid covariance (dof adj.)</td>
<td>-9.947E-07</td>
<td>-6.76588</td>
</tr>
<tr>
<td>Log likelihood</td>
<td>4256.198</td>
<td></td>
</tr>
<tr>
<td>Akaike information criterion</td>
<td>-8.285543</td>
<td></td>
</tr>
<tr>
<td>Schwarz criterion</td>
<td>-8.218121</td>
<td></td>
</tr>
</tbody>
</table>

Direct observation shows that at the two phases, the logarithmic likelihoods are very large, but the Akaike information criterion (AIC) and Schwarz criterion (SC) are small, indicating the model is good. Thus, we can discuss the short-term equilibrium relationship by analyzing the VER computations of EUA and CER futures prices at the two phases.

The EUA-CER short-term equilibrium relationship at 2ND phase goes like this: when the CER futures prices are unchanged, the t-phase variation of EUA futures prices could eliminate 0.27% of non-equilibrium error from the previous phase. When the EUA futures prices are unchanged, the t-phase variation of CER futures prices could eliminate 2.84% of non-equilibrium error from the previous phase. When the CER futures prices at 3RD_EXCL phase are unchanged, the t-phase variation of EUA futures prices could eliminate the 1.71% of non-equilibrium error from the previous phase. When the EUA futures prices are unchanged, the t-phase variation of CER futures prices could increase the 1.60% of non-equilibrium error to the previous phase.

Comparison shows that the two coefficients at both phases conform to a backward correction mechanism, and the error correction of CER futures prices is stronger than that of EUA futures prices, indicating the CER futures prices are more sensitive to market changes. At 3RD_EXCL phase, the sensitivity of EUA futures prices to the market changes is strengthened to different degrees, the correction direction of CER futures prices is changed, indicating there are many uncertainty factors at 3RD_EXCL phase.

**3.2.4. Pulse Response Analysis**

Pulse response function can be used to describe the response of an endogenous variable to the impact caused by the error item. An innovation at the value of one standard deviation (SD) is added to the stochastic error term, so as to test the influence degrees on the current value of the endogenous variable and the futures. To further describe the linkage relationship between the EUA and CER futures prices, we used the generalized impulse response function to analyze how the addition of a one-SD innovation into the random error term would affect the EUA or CER spot prices and futures prices.

The response of EUA futures prices to self-innovation at 2ND phase first maximizes to 0.0294% and then gradually stabilizes, and is nearly not impacted by the one-SD innovation from CER (Figure2), indicating the impact of self-residue from EUA would positively affect the EUA futures prices at long run. The CER futures prices at 2ND phase make a 0.0331% response to the self-innovation immediately, then drop to 0.0293% and gradually go up. On the contrary, the one-SD innovation from EUA would cause a gradually-decreasing positive effect on the CER futures prices (Figure 3).
The L_EUA_3RD_EXCL futures prices make a strongest 0.04% response to the self-innovation immediately, then drop to the bottom at fourth phase, then gradually go up and finally stabilize (Figure 4). On the contrary, the one-SD innovation from CER would bring a negative effect on the EUA futures prices since second phase. The L_CER_3RD_EXCL futures prices would, in response to a one-SD innovation, make a largest 0.097% response and then show a fluctuant positive effect (Figure 5). In response to the one-SD innovation from EUA, the CER futures prices only slightly respond and finally approach 0 with time.

In comparison, via market conduction, the EUA futures prices at 2ND and 3RD_EXCL phases both are severely impacted by self-innovation and make long-term stable positive response, but the impacts due to CER-induced innovation are very tiny. The CER futures prices, besides the effect from self-innovation, would be affected by the EUA futures prices to some degree, indicating the EUA futures prices play a very tiny dominant role in the relationship between the two price changes.

### 3.2.5. Variance decomposition

The pulse response function aims to investigate if an endogenous variable in the VAR model is impacted by innovation, whether this innovation would affect other endogenous variables; if yes, then whether this effect is positive or negative? The variance decomposition, based on the VEC model, aims to analyze the contribution of each signal to the variation of an endogenous variable.

Variance decomposition of L_EUA_2ND futures prices (Figure 6) shows that the variation of their price changes makes the largest contribution, but the contribution from CER futures prices is very weak. Variance decomposition of CER_2ND futures prices (Figure 7) shows that the contribution from EUA futures prices is very large at first, then maximizes to 44%, but then, the self-contribution is gradually strengthened with time, but since the 10th day, the contribution from EUA futures prices is still 30%.

Variance decomposition of 3RD_EXCL phase futures prices (Figs. 8, 9) show that compared with 2ND phase, the prices of both EUA and CER futures originate from the self-changes. It is indicated that the L_EUA_2ND futures prices play a guiding effect, but in 3RD_EXCL phase, there is either severe influence relation so far between EUA and CER futures prices, or a guiding effect of a certain price.

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**Figure 2.** L_EUA_2ND responds to one-SD innovation

**Figure 3.** L_CER_2ND responds to one-SD innovation

**Figure 4.** L_EUA_3RD_EXCL responds to one-SD innovation

**Figure 5.** L_CER_3RD_EXCL responds to one-SD innovation
and for carbon trading commodities together lead to the integration disappears at

Kyoto Protocol has many uncertainty factors. In recent years, many countries, especially developed countries, strengthen the discourse power in the world. Since the entrance of governmental supervision and management. First, the consciousness of pricing should be enhanced so as to confidence in the futures prices of these two common commodities.

due to the EUA futures prices to some degree, indicating the EUA futures prices play a very tiny dominant role in the relationship between the two price changes. Variance decomposition shows that the EUA futures prices at 2ND phase play a guiding effect, but in 3RD phase, there is neither severe influence relation so far between EUA and CER, nor a guiding effect of a certain price.

(3)General trends of futures prices. The EUA and CER prices both show a fluctuating downtrend. It is indicated since 3RD phase, the supply surplus of EUA and CER, slow economic recovery in Europe, and enterprise productivity decline as well as dropping demand for carbon trading commodities together lead to the reduction of enthusiasm to energy-saving and emission-reducing low-carbon economy, so the market shows low confidence in the futures prices of these two common commodities.

The above analyses show some inspirations for the establishment of carbon futures market in China and the governmental supervision and management. First, the consciousness of pricing should be enhanced so as to strengthen the discourse power in the world. Since the entrance of third phase, the second compliance from Kyoto Protocol has many uncertainty factors. In recent years, many countries, especially developed countries, become unwilling to cooperate due to consideration of their own benefits, and even withdraw from the Protocol. These uncertainty factors lead to the trading volume reduction, instability of pricing mechanism, and to more severe uncertainty in the CER-based transaction prices in China. Thus, to build a perfect market, China has to grasp the pricing power, so as to avoid international impact and interference. Second, construction of
state-wide market based on the existing local markets. Due to the heterogeneity of EUA and CER, the unsmooth market price transfer of these two products would induce price heterization. Thus, a state-wide market should be built so as to avoid price heterization. Third, the central and regional governments should enhance support to carbon finance. Since carbon finance is favorable for the climate environment, but also provides new motivity for the economic development of a country, thus it is contributive to the transition of economic growth patterns. Under the uncertainty of international environment, China should be adamant in carbon market construction and carbon finance development. Only enlarging Chinese carbon market would avoid the impact of international environment uncertainty on domestic pricing. The Chinese government should increase the capital investment into the carbon finance markets, which is manifested not only in the favorable tax policies provided by governments to the low-carbon enterprises, but is also in the intensification of carbon finance personnel training and carbon trading platform construction. Fourth, laws and regulations related to carbon finance market should be improved. After the entrance of third phase, the legal frame of carbon finance is still dependent on Kyoto Protocol, and EU ETS, so it should be further improved, which would reduce the enthusiasm of trading entities. From this viewpoint, laws are the basic foundation and strong guarantee for maintenance of market order. After an enterprise enters the carbon finance market, if its rights cannot be protected, its enthusiasm would be reduced, which is unfavorable for the sustainable development of the whole carbon finance market. The decline of trading volume and the lack of institutional guarantee are nonconductive to the transfer of the pricing mechanism. Thus, Chinese legal departments should formulate carbon finance-related laws and regulations as soon as possible and thereby guarantee the carbon finance markets could run stably.

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