# Granger causality of Carbon allowances and Carbon offsets in the Korean carbon market.

**Dong-Hoon Shin**[1]

[1] Associate professor, Dept. of Global Finance and Banking, Inha University, Incheon, South Korea.

**Email:** dhshin@inha.ac.kr

## Abstract

*In the Korean carbon market system, KAU is the most representative Carbon allowance, and KOC is an external project allowance that can be exchanged for offset allowance. In the carbon market, these two are traded at 1KAU = 1KOC, but the values of the two products do not match due to various factors. In this study, the stability of the two prices was tested and the cointegration relationship was investigated. While measuring the Granger causality of the two variables, it was found that there was a change in the causality of the two variables in the first and second transition periods of the Korean carbon market. This appears to be due to the difference between the first and second operating periods for the upper limit of the use of offsetting allowances for proof of compliance.*

## 1. Introduction

The Korean government is operating the 2050 Net-zero Carbon Committee to realize net-zero carbon by 2050, and has previously decided the '2030 NDC Raise Plan', which includes raising the national greenhouse gas reduction target (NDC) by 40% compared to 2018. The Korea Emissions Trading Scheme (K-ETS) has been operating since January 2015 as a major means of reducing GHG emissions, and the characteristics of each operating period are shown in Table 1 below. Currently, as the 3rd operating period, it is a stage of active greenhouse gas reduction and decreasing the ratio of the free allocation of allowances.

Table 1. Goals of the Korean Emissions Trading Scheme by Period

| | Phase I ('15 ~ '17) | Phase II ('18 ~ '20) | Phase III ('21 ~ '25) |
|---|---|---|---|
| Main Goal | Accumulation of experience and establishment of trading system | Reduction of significant amount of greenhouse gas | Inducing voluntary reduction in preparation for the new climate regime |
| System Operation | Improvement of system flexibility, such as the scope of offsetting recognition<br>Establishment of | Expand the scope of the trading system and raise the target<br>Advancement of various standards such as | Expansion of liquidity supply, including participation in third-party trading systems |

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|---|---|---|---|
| | infrastructure for accurate MRV execution | emission reporting and verification | |
| Allocation | Free allocation<br>Uses of the goal management system | Start allocation via auction<br>* Free: 97%, Auction: 3%, advanced allocation method such as benchmark allocation | Increase the ratio of auctioning allocation<br>* Free: 90%, Auction: 10%<br>Establishment of an advanced allocation method |

► Source : Korean Climate Change Promotion Portal

In Korea's emission trading system, companies subjected to the allocation of the emission trading system have accumulated 3 years of experience in the management of greenhouse gas(GHG) emission through the GHG and Energy Target Management System since 2012 and are participating in the emission trading system. The GHG and Energy Target Management System is designed to achieve the national mid-term GHG reduction target (reduction of national GHG emissions by 2030 to 244/1,000 of total GHG emissions in 2017) in accordance with the Basic Act of Low carbon green growth. Companies and business sites with GHG emissions and energy consumption above a certain level (50,000tCO2-eq 200TJ or more, 15,000tCO2-eq 80TJ or more) are designated as management companies.
In order to comply with K-ETS obligations, companies subject to allocation can use emission allowances obtained through the emission trading market in addition to reducing actual emissions through internal GHG reduction activities. The companies subject to the allocation allocate the emission allowances corresponding to the quota predetermined by the government in units of Korean emission allowances (KAU). If the performance of greenhouse gas reduction performed outside the boundaries of this company recognized as an external project, it receives Korea Offset Unit (KOC), an emission right for the external project. When a company subject to allocation uses KOC to comply with ETS obligations, it must be converted into Korea Credit Unit (KCU), an offsetting allowance. The use of KCU for proof of compliance had an upper limit of 10% until the 2nd operating period(Phase II), and the limit has been reduced to 5% now, the 3rd operating period(Phase III).
Therefore, the K-ETS market refers to the market where KAU, KCU, and KOC are traded. However, in the case of KCU, the trading volume of KCU is close to zero from 2018 as KOC listed in 2016 is actively traded. Since KAU and KOC are traded 1:1 in the Korean carbon market, they must be traded at the same price. However, the price difference is inevitable because there are various differences depending on the trading volume, production method, and scope of certification of the two credits. Maria Mansanet-Bataller et al. (2011) and Fatemeh Nazifi (2013) are representative studies of price differences between allowance units and offset units in EU-ETS. Maria Mansanet-Bataller et al. (2011) analyzed that micro-market factors such as trading volume and open interest, rather than structural factors such as energy prices and macroeconomic indicators, mainly affect the spread, and this is the cause of short-term arbitrage by the spread. On the other hand, Fatemeh Nazifi (2013) analyzed the energy price as a factor affecting spread

fluctuations, paying attention to the structural relationship of spread fluctuations. Park and Cho (2013) found a positive correlation with the results of studying the pattern of price difference between EUA(European Union Allowance) and sCER(secondary Certified Emission Reduction) and the determinants of the spread between the two credits in the EU-ETS market. They confirmed that the two emission credits are affected in common by coal price, financial crisis, and system operation variables, but are affected differently by policy variables such as electricity rates and CER usage restrictions, and the price difference between EUA and ERU(Emissions Reduction Unit).

This study examines the period when the price difference between KAU and KOC occurs after 2018, excluding KCU which has little trading volume, and examines the causes of the price difference. Section 2 introduces the models for Granger causality analysis and introduces the data for the analysis of this study. Section 3 describes the results of the analysis and the relationship between KAU and KOC found in this study. Section 4 summarizes the research results and future research tasks.

## 2. Models and data

In this study, I used the Granger causality test to investigate the price relationship between KAU and KOC. Before the causality test, the time series stability of the KAU and KOC data is tested. Dickey-Fuller (1981)'s Argument Dickey-Fuller unit root test (ADF Unit Root Test) is used to determine whether the time series data was stable or not. If it is not a stable time series, it is necessary to test by converting it to a stable time series through a difference.

$$\Delta X_t = \beta_0 + \alpha X_{t-1} + \sum_{i=2}^{L} \beta_0 \Delta X_{t-i+1} + \varepsilon_t, \qquad (1)$$

where $X_t$ is the price of allowances, $\Delta X_t = X_t - X_{t-1}$.

Even when the price of emission permits is unstable, a stable linear relationship can exist between the variables, which is said to be a co-integration relationship. In this study, I investigated the cointegration relationship between the two variables with the test method of Johansen (1987). If the two variables have a long-term equilibrium relationship, there can be a causal relationship in which they influence each other or that the price of one permit leads to the price of another. In the case of an unstable time series in which the cointegration relationship is established during the causality test, we use the vector error correction model (VECM) as in Equation (2).

$$\Delta Y_t = \delta + \Pi e_{t-1} + \sum_{k=1}^{p} \Gamma_k \Delta Y_{t-k} + \varepsilon_t, \text{ where } \Delta Y_t = \begin{bmatrix} \Delta KOC_t \\ \Delta KAU_t \end{bmatrix}, \Pi = \begin{bmatrix} B_1 \\ B_2 \end{bmatrix}, \Gamma_k = \begin{bmatrix} \gamma_{1k} & \gamma_{2k} \\ \gamma_{3k} & \gamma_{4k} \end{bmatrix}, \qquad (2)$$

$$e_{t-1} = KOC_{t-1} - \beta KAU_{t-1} - \alpha = [1 - \beta - \alpha] \begin{bmatrix} KOC_{t-1} \\ KAU_{t-1} \\ 1 \end{bmatrix}$$

In the case of a stable time series, we use the vector autoregressive model (VAR) of Equation (3).

$$\Delta Y_t = \theta + \sum_{k=1}^{p} \Gamma_k \Delta Y_{t-k} + \varepsilon_t, \text{ where } \Delta Y_t = \begin{bmatrix} \Delta KOC_t \\ \Delta KAU_t \end{bmatrix}, \Gamma_k = \begin{bmatrix} \gamma_{1k} & \gamma_{2k} \\ \gamma_{3k} & \gamma_{4k} \end{bmatrix}. \qquad (3)$$

If it is an unstable time series in which the cointegration relationship does not hold, we use the VAR(vector autoregression) model after converting to a stable time series through a difference. In the Granger causality test, if the null hypothesis $H_0$: '$KAU_t$ does not cause $KOC_t$ to Granger causation' is rejected, it is interpreted that $KAU_t$ Granger causes $KOC_t$. If the opposite null hypothesis is also rejected, it means that the two variables influence each other.

For the data, I used daily closing price data of KAU ($KAU_t$) and KOC ($KOC_t$) traded on the Korea Exchange (www.krx.co.kr). Since KOC started trading on May 23, 2016, I used the data after the start day. KAU is newly issued for each transition year, named by adding two digits after KAU. In other words, KAU16 has the transition year of 2016, and KAU17 has the transition year of 2017. I also used the KAU data after May 23, 2016. Therefore, this study analyzes the data of KAU16~KAU20 and tries to compare the correlation with the KOC data of the same period. Table 1 summarizes the basic statistics. On average, we can see that KOC is slightly more expensive than KAU. This contrasts with EU-ETS where CER is on average slightly more expensive than EAU.

Table 2. Basic statistics

| Period | Variables | Mean | Standard deviation | Median | Max | Min | Coefficient of Variation |
|---|---|---|---|---|---|---|---|
| 2016.06.13~ 2017.06.30 | KAU16 | 19450 | 2302.18 | 19100 | 26500 | 16500 | 0.1184 |
| | KOC | 19815 | 2129.45 | 18900 | 25200 | 15000 | 0.1075 |
| 2017.01.23~ 2018.08.09 | KAU17 | 21951 | 1876.62 | 21800 | 28000 | 20000 | 0.0855 |
| | KOC | 22525 | 1804.63 | 22200 | 28000 | 19000 | 0.0801 |
| 2018.06.22~ 2019.09.30 | KAU18 | 25986 | 3026.04 | 26250 | 39000 | 21600 | 0.1165 |
| | KOC | 26509 | 2214.54 | 25800 | 35600 | 23500 | 0.0835 |
| 2018.11.08~ 2020.09.11 | KAU19 | 30106 | 6462.21 | 28600 | 40900 | 15000 | 0.2147 |
| | KOC | 33189 | 6207.53 | 35600 | 40800 | 23500 | 0.1870 |
| 2018.11.08~ 2021.08.10 | KAU20 | 26706 | 7257.58 | 27050 | 42500 | 10500 | 0.2718 |
| | KOC | 30974 | 6280.71 | 28300 | 40800 | 21500 | 0.2028 |

For convenience, the comparison between KAU16 and KOC during the period 2016.06.13~2017.06.30 will be referred to as Case 1, and similarly, the comparison between KAU17 and KOC is Case2, the comparison between KAU18 and KOC is Case3, the comparison between KAU19 and KOC is Case4, and the comparison between KAU20 and KOC will be referred to as Case 5.

## 3. Results

First, I checked the stability of the time series through the unit root test of KAU and KOC for each case. Table 3 shows the analysis results.

Table 3. Stability test results. (I(1) test)

| Period | Variable | Data in level | | | Data in difference | | |
|---|---|---|---|---|---|---|---|
| | | Lag | Coefficient | t-stat. | Lag | Coefficient | t-stat. |
| 2016.06.13~ 2017.06.30 | KAU16 | 1 | -0.0010 | -1.152 | 0 | -0.9838*** | -15.8 |
| | KOC | 1 | -0.0005 | -0.498 | 0 | -0.9445*** | -15.19 |
| 2017.01.23~ | KAU17 | 1 | -0.0004 | -0.334 | 0 | -0.7619*** | -15.19 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2018.08.09 | KOC | 1 | -0.0006 | -0.846 | 0 | -0.6803*** | -13.9 |
| 2018.06.22~ 2019.09.30 | KAU18 | 1 | -0.0024 | -2.605 | 0 | -0.9263*** | -18.43 |
| | KOC | 1 | -0.0016 | -2.899 | 0 | -0.9886*** | -17.41 |
| 2018.11.08~ 2020.09.11 | KAU19 | 1 | -0.0001 | -0.134 | 0 | -0.8425*** | -18.29 |
| | KOC | 1 | -0.0008 | -1.830 | 0 | -0.9970*** | -21.24 |
| 2018.11.08~ 2021.08.10 | KAU20 | 1 | -0.0003 | -0.358 | 0 | -0.8619*** | -22.68 |
| | KOC | 1 | -0.0000 | -0.056 | 0 | -0.8919*** | -23.38 |

Note: *** indicates that the statistic is significant at the 1% significance level.

In all cases, KAU and KOC appeared as unstable time series of I(1) series with unit root at 1% significance level. Table 4 summarizes the results of the cointegration test using Johansen's test to check whether the level variable, which is an unstable time series, has cointegration.

Table 4. Cointegration test result

| Cases | Eigenvalue | Trace statistics | 10% critical value | 5% critical value | 1% critical value | Hypothesized No. of (CE(s)) |
|---|---|---|---|---|---|---|
| Case 1 | 0.1473 | 45.25 | 15.66 | 17.95 | 23.52 | None*** |
| | 0.0152 | 3.97 | 6.50 | 8.18 | 11.65 | At most 1 |
| Case 2 | 0.0748 | 38.00 | 15.66 | 17.95 | 23.52 | None*** |
| | 0.0231 | 8.78 | 6.50 | 8.18 | 11.65 | At most 1** |
| Case 3 | 0.1080 | 42.26 | 15.66 | 17.95 | 23.52 | None*** |
| | 0.0213 | 6.71 | 6.50 | 8.18 | 11.65 | At most 1* |
| Case 4 | 0.0362 | 17.03 | 15.66 | 17.95 | 23.52 | None* |
| | 0.0005 | 0.24 | 6.50 | 8.18 | 11.65 | At most 1 |
| Case 5 | 0.0210 | 16.76 | 15.66 | 17.95 | 23.52 | None* |
| | 0.0034 | 2.34 | 6.50 | 8.18 | 11.65 | At most 1 |

Note: *** indicates 1%, ** indicates 5%, * indicates 10%, meaning that the statistic is significant at the significance level.

In Case 1, KAU16 vs KOC, the null hypothesis that there is no cointegration relationship (None) under the 5% significance level is rejected. However, under the 5% significance level, the null hypothesis that there is less than one cointegration relationship (At most 1) cannot be rejected. Therefore, we can confirm that there is at least one cointegration relationship.

These synchronization phenomena are observed at least one co-integration relationship from Case 1 to Case 3. However, in KAU19 and KAU20 belonging to Case 4 and Case 5, the null hypothesis that there is no cointegration relationship at the 10% significance level can be rejected. At the 10% significance level, KAU and KOC were analyzed to establish a long-run equilibrium relationship in all periods. Therefore, I performed causality tests for all cases using the VECM model. The number of lags of the model was determined with reference to the SIC(Schwarz-Bayesian Information Criterion). Table 5 summarized the test results.

Table 5. The number of lags in VECM and Granger Causality

| Cases | # of lags | KAU->KOC(F stat.) | KOC->KAU(F stat.) | Granger Causality(5%) |
|---|---|---|---|---|
| Case 1 | 1 | 4.6775** | 51.576*** | KOC<->KAU16 |
| Case 2 | 2 | 4.9328*** | 21.765*** | KOC<->KAU17 |
| Case 3 | 1 | 0.7319 | 10.755*** | KOC->KAU18 |
| Case 4 | 1 | 4.655** | 11.249*** | KOC<->KAU19 |
| Case 5 | 1 | 7.6725*** | 10.306*** | KOC<->KAU20 |

Note: *** indicates 1%, ** indicates 5%, * indicates 10%, meaning that the statistic is significant at the significance level.

As a result of referring to the SIC, only Case 2 had 2 lags in its model, and other Cases had 1 lags in their model, and a causal relationship leading to price change was analyzed for every case. The results in Table 4 indicated that KOC was Granger causal to KAU throughout all periods. Except for Case 3, it was analyzed that KOC and KAU had mutual Granger causality in most of the time. What is interesting is that the degree of Granger causal of KOC to KAU was stronger in the beginning, but on the contrary, the degree of Granger causal of KAU to KOC gradually increased over time.

As a result of the analysis, the causal strength of KOC and KAU was strong during Case 1 and Case 2, which belong to the first transition year. There can be several reasons for this. Since KOC is listed on the exchange in the first and second years, it does not seem to depend much on the price of KAU, as a leading market, in the pricing mechanism. However, it is analyzed that the strength of the mutual causal relationship between the two emission permits has weakened significantly from the second transition year. This began to impose an upper limit of 10% on the use of KCU for proof of compliance from the 2nd operating period, and KOC converted to KCU seems to have been affected by the rule.

## 4. Conclusion

This study analyzed the cointegration and Granger causality between KAU, which is an allocated allowance, and KOC, which is an offsetting allowance, among K-ETS emission allowance products from 2016 to 2020. This study is meaningful in that it looked at the Granger causality between KAU and KOC, the most representative products in the Korean carbon market, for the longest period. I summarize the main results of this study as follows.

The mutual Granger causality between KAU and KOC had observed in 2016 and 2017, which belonged to the first operating period, but the strength of causality was stronger in the direction of KOC to KAU. However, in the second operating period, the degree of KOC causation of KAU became very weak, and the degree of KAU causation of KOC was gradually getting stronger. There may be various reasons for this, but the one reason may be that the rule of the 10% cap on the use of offsetting allowances for proof of compliance in the second operating period had affected to the weakness. Other causes may be the growth of independent markets, different pricing systems, and asymmetry among consumers of carbon credits. We need further researches to find the reasoning.

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