Dynamic Price Linkage and Volatility Structure Model between Carbon Markets

Takashi Kanamura[1]

[1]Kyoto University, Japan

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Outline

1. Objectives and Results
2. The Correlation Model
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Background

- Carbon markets are interrelated with one another due to the political linkage, e.g., EU's Linking Directive effective in 2004.
- By using the linkage between EUAs and secondary CERs, market players may conduct arbitrage trading of sell-high and buy-low strategy, referred to as EUA-sCER swap.
- The political linkage between the two markets will affect the correlation structure of carbon prices.
- It is well known that energy prices affect carbon prices in a different way depending on the carbon market structure of energy related and unrelated emission reduction technologies.
- Energy prices will also characterize the correlation structure accompanied by the volatility structure.

EUA and sCER Futures Prices in December 2009

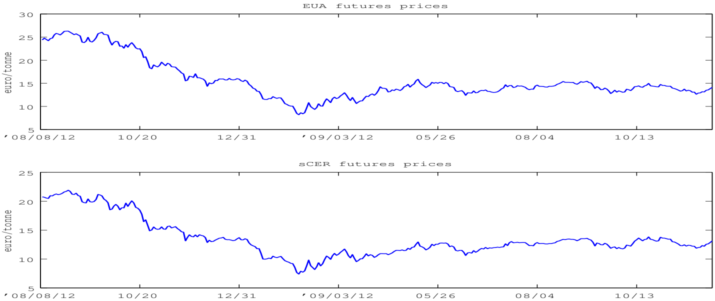

Figure: EUA and sCER Futures Prices

EUA and secondary CER (sCER) futures prices delivered in December 2009 seem to move together as an empirical evidence of the linkage. The high correlations are expected both in high and low carbon prices.

Literature Survey

- Fehr and Hinz (2006) propose an equilibrium price model for EUA prices taking into account the fuel switching between natural gas and coal fired power plants.
- Benz and Trück (2009) employ AR-GARCH Markov switching price return model to capture the regime shifts between different phases of EU-ETS and the heteroskedasticty.
- Daskalakis, Psychoyios, and Markellos (2009) compare existing diffusion and jump diffusion models, resulting in the favor of the Geometric Brownian motion with jumps to fit historical EUA spot prices.
- Paolella and Taschini (2008) also propose the mixed normal and mixed stable GARCH models to capture the heavy tail and volatility clustering in the U.S. SO_2 permits and EUA price returns.

Literature Survey (Cont'd)

- While these empirical studies are keen on carbon price models and their empirical analyses for a single carbon market, they do not seem to care about characteristics of the correlation structure between carbon markets.
- Grüell and Taschini (2010) assessed the linkage between emission trading schemes by focusing on the price convergence, but unfortunately they do not use the carbon price model for the linkage assessment.
- Chevallier (2011) provides evidence of time-varying correlations between EUAs and CERs.

Literature Survey (Cont'd)

- Mansanet-Bataller, etal (2011) and Medina, Pardo and Pascual (2013) show that the spread between the two markets is driven by EUA prices.
- Finally, Mizrach (2012) notes the lack of convergence between EUA and CER prices.
- The studies are quite important to understand EUA-sCER price spreads empirically.
- But they employ existing econometric models, not supply-demand based models for carbon credits.
- To this end, the investigation of the two carbon markets linkage may not be conducted so far using the supply-demand based carbon price model.

The objectives

- We model the correlations between EUA and sCER price returns using the supply-demand relationship between twofold carbon markets, i.e., marginal abatement cost curve and emission reduction volume by taking into account of EUA-sCER swap transaction and energy prices.

The results

(1) We propose the correlation model which reflects financial players' activities of EUA-sCER swap transaction and the influence of energy prices on EUA prices.

(2) The model suggests that the correlations increase when the swap transaction increases or energy prices fall, translated into the opposite EUA price movements of EUA price rise or fall, respectively.

(3) It is shown that the volatility in carbon prices decreases in the prices using an inverse Box-Cox function MAC curve with a positive parameter, referred to as "leverage effect" often observed in security markets.

Motivation for our model

- Carbon prices are strongly affected by the supply-demand relationship of marginal abatement cost and emission reduction.
- A certain amount of carbon assets in a carbon market can be used in the other carbon market, resulting in the volumetric linkage due to the swap transaction, e.g., EUA-sCER swap.
- Energy prices will affect carbon prices differently regarding EUA and CER markets because the internal abatement expressed by the MAC curve is conducted in different ways.
- We want to model the correlation based on the MAC curve and emission reduction volume taking into account EUA-sCER swap and energy prices in order to examine the interaction between EUA and sCER prices.

The correlation model framework

Assuming emission reduction inelasticity to prices in a short period of time, we have the equilibrium prices of EUA and sCER, respectively using emission reduction volume and MAC curve.

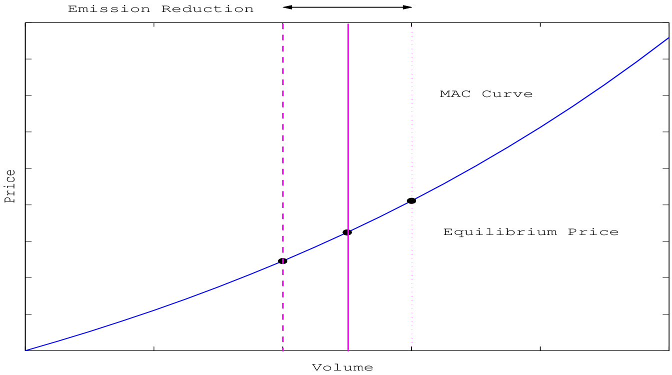

Figure: Supply & Demand for Carbon Markets

Emission reduction volume (Demand Side)

- V_t and D_t represent emission reduction volume regarding EUA and sCER, resp. calculated by emission minus emission reduction target which allows for negative value:

$$dV_t = \mu_V dt + \sigma_V dw_t, \;\; dD_t = \mu_D dt + \sigma_D dv_t. \tag{1}$$

- We assume that EUA prices are determined by the emission reduction and marginal abatement cost in the EU ETS: the total reduction in the EU X_t is set to be V_t irrelevant to sCER swap volume B_t.
- In contrast, the total reduction volume regarding sCER Y_t is assumed to be the sum of D_t and B_t.

$$X_t = V_t, \;\; Y_t = D_t + B_t. \tag{2}$$

EUA-sCER Swap

EUA can be exchanged by sCER in the EU ETS. It will be valuable and sCER swap volume will rise under wide EUA-sCER price spread. It is known that the price spread becomes narrow when EUA price decreases, i.e., emission reduction in the EU ETS becomes low.

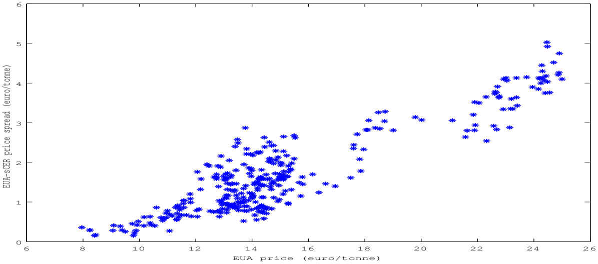

Figure: EUA Spot P. and EUA-sCER P. Spread

sCER swap volume will be positively correlated with EU emission reduction volume ($0 \leq \rho_{BV}(V) \leq 1$).

EUA-sCER Swap Modeling

- The swap transaction volume for the sCER is defined by B_t.

$$dB_t = \mu_B dt + \sigma_B dz_t. \quad (3)$$
$$E[dz_t dw_t] = \rho_{BV}(V)dt, \quad (4)$$
$$\text{where } 0 \leq \rho_{BV}(V) \leq 1, \quad (5)$$

$E[dv_t dz_t] = \phi dt$ and $E[dw_t dv_t] = \varphi dt$ (const. $\phi, \varphi > 0$) in the long run.

- More importantly when EUA price, i.e., EUA demand, is high, it is also considered that the market participants may try to obtain the EUA-sCER swap arbitrage opportunity more, resulting in the high correlation between the EUA and sCER volume.
- That is why the correlation is characterized by $\frac{\partial \rho_{BV}}{\partial V} > 0$.

MAC curve (Supply Side)

- EUA prices are strongly affected by the fuel switching costs of crude oil prices via the MAC curve, while sCER prices are determined by the different risk factors from oil prices.
- When energy prices rise, the order of the cheaper emission reduction measure changes in the direction of the horizontal axis since the impact of energy prices on each technology marginal abatement cost is different.
- The impact of energy prices on the MAC curve is observed as the horizontal shift of the MAC curve.

MAC curve (Supply Side) Cont'd

- We define by $f(\cdot)$ an increasing MAC curve for EUA positively affected by energy prices E_t and emission reduction x_t:

$$P_t = f(x_t + kE_t), \tag{6}$$

- k is expected as a positive value because the MAC curve rises in the energy prices given by

$$dE_t = \mu_E dt + \sigma_E(E) d\eta_t, \tag{7}$$

where $d\eta_t$ only possesses positive correlation with dw_t ($E[d\eta_t dw_t] = \omega dt$) because the influence may be highlighted only in the EU-ETS due to the fuel switching and where $\frac{\partial \sigma_E(E)}{\partial E} > 0$ from inverse leverage effect.

- We define by $g(\cdot)$ an increasing MAC curve of sCER which is immune to energy prices.

$$S_t = g(y_t), \tag{8}$$

where S_t represents sCER prices for the reduction y_t.

The correlation model

Considering that carbon prices are given by the increasing MAC curve function of the emission reduction and using Ito's Lemma, we recover the correlation model between EUA and sCER price returns:

$$\frac{dP_t}{P_t} = \mu_P dt + \sigma_P d\nu_t, \tag{9}$$

$$\frac{dS_t}{S_t} = \mu_S dt + \sigma_S du_t, \tag{10}$$

$$\begin{aligned} \rho_{PS} &\equiv \frac{1}{dt}\text{Corr}\left(\frac{dP_t}{P_t}, \frac{dS_t}{S_t}\right) \\ &= \frac{(\varphi\sigma_D + \rho_{BV}(V)\sigma_B)\sigma_V}{\sqrt{\sigma_D^2 + \sigma_B^2 + 2\sigma_B\sigma_D\phi}\sqrt{k^2\sigma_E(E)^2 + \sigma_V^2 + 2k\sigma_E(E)\sigma_V\omega}}, \end{aligned} \tag{11}$$

The correlation is the function of V and E.

The correlation model (cont'd)

$$\mu_P = \frac{f'}{f}(k\mu_E + k'E + \mu_V) + \frac{1}{2}\frac{f''}{f}(k^2\sigma_E^2 + \sigma_V^2 + 2k\sigma_E\sigma_V\omega), \quad (12)$$

$$\sigma_P = \frac{f'}{f}\sqrt{k^2\sigma_E^2 + \sigma_V^2 + 2k\sigma_E\sigma_V\omega}, \quad (13)$$

$$d\nu_t = \frac{1}{\sqrt{k^2\sigma_E^2 + \sigma_V^2 + 2k\sigma_E\sigma_V\omega}}(k\sigma_E d\eta_t + \sigma_V dw_t), \quad (14)$$

$$\mu_S = \frac{g'}{g}(\mu_D + \mu_B) + \frac{1}{2}\frac{g''}{g}(\sigma_D^2 + \sigma_B^2 + 2\sigma_B\sigma_D\phi), \quad (15)$$

$$\sigma_S = \frac{g'}{g}\sqrt{\sigma_D^2 + \sigma_B^2 + 2\sigma_B\sigma_D\phi}, \quad (16)$$

$$du_t = \frac{1}{\sqrt{\sigma_D^2 + \sigma_B^2 + 2\sigma_B\sigma_D\phi}}(\sigma_D dv_t + \sigma_B dz_t). \quad (17)$$

Volatility structure: Leverage effect

We assume the inverse Box-Cox MAC curves of carbon assets with $a_1, a_2 > 0$: the MAC curves are flatter than the exponential.

$$P = f(x) = \left(1 + \frac{a_1 x}{c_1}\right)^{\frac{1}{a_1}}, \quad S = g(y) = \left(1 + \frac{a_2 y}{c_2}\right)^{\frac{1}{a_2}}, \tag{18}$$

The spot price return volatilities for EUA and sCER are given by

$$\sigma_P = \frac{\bar{\sigma}_P}{c_1} P_t^{-a_1}, \quad \sigma_S = \frac{\bar{\sigma}_S}{c_2} S_t^{-a_2}, \tag{19}$$

where $\bar{\sigma}_P = \sqrt{k^2\sigma_E^2 + \sigma_V^2 + 2k\sigma_E\sigma_V\omega}$ $\bar{\sigma}_S = \sqrt{\sigma_D^2 + \sigma_B^2 + 2\sigma_B\sigma_D\phi}$.
When $a_1, a_2 > 0$, $\frac{\partial \sigma_P}{\partial P}$ and $\frac{\partial \sigma_S}{\partial S}$ are negative: the leverage effect in spot prices observed in security markets (Black (1975)).

Conclusions

(1) We have proposed the correlation model which reflects both of financial players' activities of EUA-sCER swap transaction and the influence of energy prices on EUA prices.

(2) The model suggested that the correlations increase when the swap transaction increases or energy prices fall, translated into the opposite EUA price movements of EUA price rise or fall, respectively.

(3) It was shown that the volatility in carbon prices decreases in the prices using an inverse Box-Cox function MAC curve with a positive parameter, referred to as "leverage effect" often observed in security markets.