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Research Article

Empirical Evidence on Time-Varying Hedging Effectiveness of Emissions Allowances under Departures from the Cost-of-Carry Theory

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Under departures from the cost-of-carry theory, traded spot prices and conditional volatility disturbed from futures market have significant impacts on futures price of emissions allowances, and then we propose time-varying hedge ratios and hedging effectiveness estimation using ECM-GARCH model. Our empirical results show that conditional variance, conditional covariance, and their correlation between between spot and futures prices exhibit time-varying trends. Conditional volatility of spot prices, conditional volatility disturbed from futures market, and conditional correlation of market noises implied from spot and futures markets have significant effects on time-varying hedge ratios and hedging effectiveness. In the immature emissions allowances market, market participants optimize portfolio sizes between spot and futures assets using historical market information and then achieve higher risk reduction of assets portfolio revenues; accordingly, we can obtain better hedging effectiveness through time-varying hedge ratios with departures from the cost-of-carry theory.

1. Introduction

Greenhouse gas (GHG) emission is an ever-increasingly hot topic in the 21st century for alarming phenomena of global warming and extreme climate deterioration. Most of the scientists and politicians believe that emissions trading scheme is a cost-effective market scheme in order to control GHG emissions. Since the launch of the European Union emissions trading scheme (EU ETS) in 2005, CO_2 emissions allowances have become valuable commodities which can be traded in CO_2 emissions allowances markets. Spot, futures, options, and other financial products of emissions allowances are important financial tools for market participants to increase assets portfolio revenues and achieve higher risk reduction. In recent years emissions allowances markets have become the most promising and are quickly growing markets in global commodities markets.

Spot and futures prices of emissions allowances depend on expected market scarcity induced by demand and supply quantity in the emissions allowances market. An early study of emissions allowances by Benz and Truck [1, 2] found that a good many complex factors such as GHS emissions reduction plan and regulation policy, low-technology promotion and application, energy prices volatility, and energy efficiency and extreme temperature changes have significant impacts on market scarcity. Seifert et al. [3], Daskalakis et al. [4], and Conrad et al. [5] asserted that spot and futures prices of emissions allowances have higher time-varying trends, spot prices follow asymmetric GARCH process, and accordingly spot assets exhibit higher market risks. Montagnoli and de Vries [6] endorsed that, in the Pilot phase, immature emissions allowances markets induce lower market efficiency, while market efficiency has better recovery signs in the Kyoto phase. Zhang and Wei [7] examined that favorable and unfavorable market information exhibits greater market overreaction induced by lower market efficiency in the Pilot phase, and emissions allowances prices have obvious divergent and unpredictable trends. Arouri et al. [8] presented that spot and futures prices have nonlinear dynamics correlations between spot and futures returns, and their volatilities exhibit asymmetric and nonlinear trends. Immature emissions markets push up higher trading risks of spot prices, and market participants can gain instable investment revenues through optimizing assets portfolio policies. Based on cost-of-carry theory, Chang et al. [9] found that market participants adjust assets portfolio policies of futures contracts with different maturities and then they can attain excess exchange options value.

A good many complex factors bring about low efficiency and overreaction of price in the emissions allowances market. These complex market factors exert greater market price shock; however, price shock effectiveness exhibits a tremendous difference in time and channels of spot and futures prices in the immature emissions allowances markets. Current emissions allowances markets are weakly effective markets; they exhibit market bias, transaction cost, and market overreaction. In the immature emissions allowances markets, unexpected market information has a different change speed of spot and futures prices in the short term, emissions allowances markets exhibit a significant lead-lag relationship between between spot and futures prices, and the theoretical and traded futures prices exhibit time-varying deviation trends.

Futures mispricing errors are greater than market transaction cost, and then market paritcipants can achieve extra arbitrage revenues through adjusting portfolio sizes between spot and futures assets. Under departures from the cost-of-carry theory, historical market information, conditional variance, and conditional correlation implied from emissions allowances futures markets have significant impacts on time-varying hedge ratios and hedging effectiveness. It is urgent for market participants to know how to increase portfolio revenues and decrease returns risk reduction of emissions allowances assets between spot and futures under departures from the cost-of-carry theory.

The main innovation of this paper is that, under departures from the cost-of-carry theory, conditional volatility of spot prices, conditional volatility disturbed from futures market, and conditional correlation of market noises implied from spot and futures markets have significant effects on time-varying hedge ratios and hedging effectiveness. These empirical results are helpful for market participants to effectively optimize portfolio sizes between spot and futures assets using historical market information and achieve higher risk reduction of assets portfolio revenues. The remainder of our paper is organized as follows. Section 2 explains cost-of-carry theory. Section 3 proposes time-varying hedge ratios model under departures from the cost-of-carry theory. Section 4 presents conditional volatility disturbed from futures market and conditional correlation of market noises between spot and futures. Section 5 descripts data samples source. Section 6 discusses empirical results of conditional volatility and conditional correlation. Section 7 estimates and discusses empirical results of time-varying hedge ratios and hedging effectiveness. Section 8 provides a brief conclusion.

2. Cost-of-Carry Theory

Based on a pioneering study of cost-of-carry theory by Working [10] and Brennan [11], in the complete emissions allowances market, assumed emissions allowances markets have no transaction costs, no arbitrage behavior, and no storage costs; S_t denotes spot price of emissions allowances, $F^*_{t,T}$ denotes theoretical price of futures contracts for maturity T at time t, and r is the continuously compounded risk-free interest rate. Based on the cost-of-carry theory, the theoretical futures price is equal to

$$F^*_{t,T} = e^{(r-\delta)(T-t)} S_t, \quad (1)$$

where δ denotes convenience yield of emissions allowances and $r-\delta$ denotes cost-of-carry of emissions allowances; the logarithmic equation (1) can be expressed as follows:

$$f^*_t = s_t + (r-\delta)(T-t), \quad (2)$$

where $s_t = \ln S_t$, $f^*_t = \ln F^*_{t,T}$ denote the logarithm of spot price and theoretical futures price. Based on cost-of-carry theory, emissions allowances market is effective, spot and futures prices should keep synchronous correlation, and spot price volatility is similar to futures price volatility. Spot and futures prices keep similar change speeds, and they exhibit no lead-lag relationship. In the immature emissions allowances markets, emissions allowances markets exhibit transaction costs, asymmetric market information, excess capital demand, and unexpected market scarcity, and the theoretical and traded futures prices exhibit greater deviation errors according to the cost-of-carry model. Immature emissions allowances market produces a lead-lag relationship between spot and futures market returns, as well as between their volatilities. It may be possible to anticipate price motion trend and reduce revenues risk reduction in one market from historical market information in other markets and present a relevant question using historical information in futures market as a hedging instrument for risky assets portfolios.

3. Time-Varying Hedge Ratios

In order to achieve market arbitrage, market participants optimize their assets portfolio policies between spot and futures using the price-clustering effects. Rich quota distribution of emissions allowances and lower trading volume in futures market induced the overraction of emissions allowances market, then push greater difference in time and pannels induced by market shocks. These market shocks induce that short-run equilibrium price in futures market is deviated from long-run equilibrium prices, price distortions in futures market made market participants attain many arbitrage opportunities, so short-term market speculations are active. Based on hedging theory, minimum variance of hedge ratios is equal that conditional covariance between spot and futures is divided by conditional variance of futures prices. Wilson [12] and Lien and Tse [13] have examined that, if spot prices are similar to futures prices, optimal hedge ratios are equal to regression coefficients between spot and futures using linear regression equation, and hedge ratios are constant. If spot and futures prices exhibit different changing speed, market investors adjust assets portfolio sizes between spot and futures according to previous market information set, and as a result optimal hedge ratios exhibit time-varying trends.

Assuming spot price and theoretical futures price of emissions allowances follow geometric Brownian process, accordingly

$$dS_t = \mu_{s,t} S_t dt + \sigma_{s,t} S_t dz_{1,t},$$
$$dF^*_{t,T} = \mu_{f,t} F^*_{t,T} dt + \sigma_{s,t} F^*_{t,T} dz_{1,t}, \quad (3)$$

where $\mu_{s,t}$, $\sigma_{s,t}$ denote instantaneous returns and volatility of spot prices, and the theoretical futures prices returns are equal to $\mu_{f^*,t} = \mu_{s,t} + (r - \delta)$. dz_1 denotes a standard Wiener process, $dz_{1,t} = \varepsilon_{1t}\sqrt{dt}$, spot market noise of emissions allowances follows standard normal distribution, and $\varepsilon_{1,t} \sim N(0,1)$. In the immature emissions allowances markets, the theoretical futures prices of emissions allowances are deviated from the traded futures prices under departures from the cost-of-carry theory. Based on the conclusion endorsed by Lafuente and Novales [14], we introduce the second market noise in order to correct market prices difference as follows:

$$dF_{t,T} = \mu_{f,t} F_{t,T} dt + \sigma_{s,t} F_{t,T} dz_{1,t} + \sigma_{c,t} F_{t,T} dz_{2,t}, \quad (4)$$

where $F_{t,T}$ denotes the traded futures prices of emissions allowances, $\sigma_{c,t}$ denotes the conditional volatility disturbed from emissions allowances futures market, and $dz_{2,t} = \varepsilon_{2,t}\sqrt{dt}$; market noise implied from emissions allowances futures market follows standard normal distribution, $\varepsilon_{2,t} \sim N(0,1)$. Based on (3) and (4), conditional correlation coefficient between spot and futures returns is equal to

$$\rho_{sf,t} = \frac{\operatorname{Cov}\left((dS_t/S_t dt), (dF_{t,T}/F_{t,T} dt)\right)}{\sqrt{\left[\operatorname{Var}_t(dS_t/S_t dt)\right]}\sqrt{\operatorname{Var}(dF_{t,T}/F_{t,T} dt)}}$$
$$= \frac{\sigma^2_{s,t} + \rho_{12,t}\sigma_{s,t}\sigma_{c,t}}{\sqrt{\sigma^2_{s,t}\left(\sigma^2_{s,t} + \sigma^2_{c,t} + 2\rho_{12,t}\sigma_{s,t}\sigma_{c,t}\right)}}. \quad (5)$$

Here $\rho_{12,t}$ denotes instantaneous correlation coefficient between spot market noise ε_1 and futures market noise ε_2 and $\rho_{sf,t}$ denotes instantaneous conditional correlation coefficient between spot and futures returns. If $\sigma^2_{ct} = 0$, spot and futures prices of emissions allowances exhibit similar market volatility, and then spot and futures prices have completely positive correlation.

Where we assume that the evolution of futures market returns is driven by heteroscedastic, geometric Brownian motion process, we incorporated a market-specific noise into the dynamics of theoretical futures returns; this market noise motivation produces a spread between the theoretical and traded futures price. Hence, spot and futures markets cannot share an identical source of volatility against the cost-of-carry model. We can estimate the motivation of spot and futures market returns as well as their volatilities and correlation of market noises disturbed from spot and futures markets using historical prices data in spot and futures markets. Accordingly, market participants take good use of historical market information and market noise disturbance implied from the futures markets and then optimize assets portfolio policies between spot and futures; accordingly, market participants can achieve stable arbitrage market revenues.

Spot prices of emissions allowances exhibit greater returns risk; market investors optimize portfolio sizes between spot and futures in order to decline assets investment risks. Assuming ϕ_{t-1} denotes market information set at time $t-1$, the hedgers buy X spot quantity of emissions allowances at time $t-1$, while selling Y futures quantity, and then hedge ratio is equal to $h_{t-1} = Y/X$. Based on a pioneering study of hedging theory by Johnson [15], the portfolio return in the period $(t-1, t)$ is equal to

$$R_{ht} = \Delta s_t - h_{t-1}\Delta f_t. \quad (6)$$

Here h_{t-1} is hedge ratio for period $t-1$, s_t, f_t represent the logarithm of spot price, of futures price for period t, $\Delta s_t = s_t - s_{t-1}$, $\Delta f_t = f_t - f_{t-1}$ are respectively the spot and futures returns for period t. Wilson [12] and Lien and Tse [13] have concluded that conditional variances estimate assets portfolio risks by using market information set at time $t-1$ as follows:

$$\operatorname{Var}\left(R_{ht} \mid \phi_{t-1}\right) = \operatorname{Var}\left(\Delta s_t \mid \phi_{t-1}\right) + h^2_{t-1}\operatorname{Var}\left(\Delta f_t \mid \phi_{t-1}\right)$$
$$- 2h_{t-1}\operatorname{cov}\left(\Delta s_t, \Delta f_t \mid \phi_{t-1}\right). \quad (7)$$

Lafuente and Novales [14] endorsed that minimum variance hedge ratio using minimum hedging risk is equal to

$$h^* = \frac{\operatorname{cov}\left(\Delta s_t, \Delta f_t \mid \phi_{t-1}\right)}{\operatorname{Var}\left(\Delta f_t \mid \phi_{t-1}\right)} = \frac{\sigma^2_{s,t} + 2\rho_{12,t}\sigma_{s,t}\sigma_{c,t}}{\sigma^2_{s,t} + \sigma^2_{c,t} + 2\rho_{12,t}\sigma_{s,t}\sigma_{c,t}}, \quad (8)$$

where $\operatorname{cov}(\Delta s_t, \Delta f_t \mid \phi_{t-1})$ denotes the covariance between spot and futures under market information set ϕ_{t-1} and h^* denotes optimal hedge ratio. From (8), when spot and futures markets engender new market information, information set ϕ_{t-1} exhibit time-varying trends, and then optimal hedge ratios exhibit time-varying trends.

4. Conditional Volatility and Correlation Estimation

Based on higher degree of liquidity in the spot market relative to the futures market, these market overreactions have more quick transition speed of spot prices relative to futures prices. In traded CO_2 emissions allowances markets, the conditional covariance matrix between spot prices and futures prices showed strongly time-varying trends. The OLS hedging cannot exhibit that time-varying price trends and lead-lag relationship have significant impacts on hedge ratio and hedging effectiveness and then decrease portfolio returns risk of emissions allowances assets. Accordingly optimally time-varying hedge ratios exhibit significantly time-varying trends. Error-correction model (ECM) is a dynamic model based on correlations in returns of two underlying assets; ECM reflects that short-term deviation is away from long-term equilibrium. Accordingly ECM considers nonstationary prices of both spot and futures, long-run equilibrium, and short-run dynamics. A bivariate error-correction model with GARCH perturbations is used to estimate the conditional second moments of market returns.

Here we assume price-clustering effects of both spot and futures are symmetric process in order to estimate conditional volatility and correlated coefficients of market noises implied from futures market. In following section, the hedgers can attain optimally time-varying hedge ratios and hedging effectiveness using ECM-GARCH.

Lien et al. [16], Lien and Yang [17], and Peng and Ye [18] proposed that previously historical market information has a significant impact on prices of both spot and futures; here the basis $\varepsilon_{t-1} = s_{t-1} - f_{t-1}$ denotes the error-correction term, incorporated into the GARCH model, as follows:

$$\begin{aligned}\Delta s_t &= \alpha_s \left(s_{t-1} - f_{t-1}\right) + \xi_{st},\\ \Delta f_t &= \alpha_f \left(s_{t-1} - f_{t-1}\right) + \xi_{ft},\\ \sigma^2_{st} &= a_s + b_s \xi^2_{s(t-1)} + c_s \sigma^2_{s(t-1)},\\ \sigma^2_{ft} &= a_f + b_f \xi_{s(t-1)} + c_f \sigma_{f(t-1)},\\ \sigma_{sft} &= a_s a_f + b_s b_f \xi_{s(t-1)} \xi_{f(t-1)}\\ &\quad + c_s c_f \sigma_{sf(t-1)}.\end{aligned} \tag{9}$$

Based on (9), we can estimate conditional variance coefficients of spot price and of futures price, conditional covariance coefficient between spot and futures. Conditional variance of futures prices of emissions allowances can be expressed using (3) and (4) as follows:

$$\sigma^2_{ft} = \sigma^2_{st} + \sigma^2_{ct} + 2\rho_{12t}\sigma_{st}\sigma_{ct}, \tag{10}$$

$$\sigma_{sft} = \sigma^2_{st} + \rho_{12t}\sigma_{st}\sigma_{ct}. \tag{11}$$

We can propose a new equation (12) using (11) as follows:

$$\rho_{12t}\sigma_{st} = \frac{\sigma_{sft} - \sigma^2_{st}}{\sigma_{ct}}. \tag{12}$$

Substituting (12) into (10), conditional volatility disturbed from emissions allowances futures market can be expressed as follows:

$$\sigma^2_{ct} = \sigma^2_{st} + \sigma^2_{ft} - 2\sigma_{sft}. \tag{13}$$

Substituting (12) into (10), conditional correlation coefficient of markets noises implied from spot and futures markets is

$$\rho_{12t} = \frac{\sigma_{sft} - \sigma^2_{st}}{\sigma_{st}\sqrt{\sigma^2_{st} + \sigma^2_{ft} - 2\sigma_{sft}}}. \tag{14}$$

Our model has four specific features as follows. Firstly, it incorporates long-term equilibrium relationship both spot and futures prices. Secondly, it takes into account cross-market interactions between market returns and volatilities. Thirdly, it does not impose constant conditional correlation coefficients. Fourthly, it captures seasonal pattern for both spot and futures market volatilities. Our model specification and technique estimation allow us to capture stochastically seasonal pattern for market volatilities of emissions allowances rather than through deterministic variables. Our estimations imply a less than perfect correlation between spot and futures returns and lead to an optimal hedge below one to hedge spot assets portfolio, without losing any hedging effectiveness in ex-ante simulations of hedging strategies using traded data.

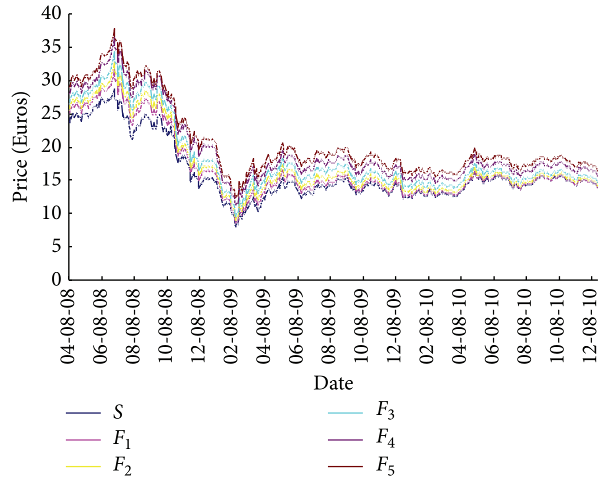

FIGURE 1: Spot and futures prices of emissions allowances.

5. Data Source

Since the introduction of emissions allowances markets in the European Union in 2005, there are two phases: the Pilot phase (2005–2007) and the Kyoto phase (2008–2012). There are three flexible schemes in the Kyoto protocol: emissions trading scheme (ETS), clean development scheme (CDM), and joint implementation (JI). One European Union allowance (EUA) has the right to emit one tone CO_2 into the atmosphere under the EU ETS. The minimum trading volumes for each futures contract are 1,000 tons of CO_2 equivalent. EUA spot samples are from Bluenext exchange which which has become the most liquid spot trading platform; EUA futures samples are from ICE exchange which has become the most liquid futures trading platform. We choose daily settlement prices for EUA futures contracts with different maturities from December 2010 to December 2014. The trading of futures contracts with vintages December 2013 and December 2014 were started on April 8, 2008. Considering the continuity and availability of numerical samples, we select that date samples cover the period from April 8, 2008 to December 20, 2010 in the Kyoto phrase.

In Figure 1, S denotes spot price of CO_2 emissions allowances, F_1 denotes EUA futures contracts that are the closest to maturity, F_2 denotes the second closest to maturity, and F_3, F_4, and F_5 are defined similarly. From Figure 1, we obviously observe that CO_2 price series both spot and futures with

Table 1: Statistical description of conditional volatility with different maturities disturbed from futures market ($\times 10^{-4}$).

Conditional volatility	Mean	Standard deviation	Maximum	Minimum
cvc_1	2.3389	2.5710	24.3276	0.4901
cvc_2	2.2851	2.5063	24.1736	0.4827
cvc_3	2.2067	2.4255	23.8514	0.4679
cvc_4	2.0228	2.1359	19.4869	0.4219
cvc_5	2.0486	2.1352	19.1370	0.4211

different maturities exhibit similarly time-varying trends throughout data sample period.

6. Empirical Discuss of Conditional Volatility and Correlation

6.1. Conditional Volatility σ_{ct}^2 Estimation Disturbed from Futures Markets. In Figure 2 and Table 1, we estimate conditional volatility σ_{ct}^2 with different maturities disturbed from futures markets using ECM-GARCH (1, 1) model. $cvc1$ denotes conditional volatility of futures prices that are closest to maturity, $cvc2$ denotes conditional volatility with the second closest to maturity, and $cvc3$, $cvc4$, and $cvc5$ are defined similarly. Seen from Figure 2, conditional volatility with different maturities disturbed from futures markets exhibits a time-varying trend. Assuming conditional volatility is constant, static hedge ratio is inappropriate to measure trading risk of emissions allowances. Based on previous historical market information set, we can estimate time-varying hedge ratios using ECM-GARCH (1, 1) model, and then market participants can effectively decrease market trading risks of assets portfolio. From Table 1, mean values of conditional volatility with different maturities disturbed from futures markets are all positive and standard deviations exhibit obvious decline trends with an increase of time-to-maturity. These results show that market noises implied from futures market have higher impacts on conditional volatility of futures contract with shorter time-to-maturity, while they have lower impacts on conditional volatility of futures contract with longer time-to-maturity.

6.2. Conditional Correlation Estimation of Market Noises. In Figure 3 and Table 2, we estimate conditional correlation of market noises between spot and futures, cr_{121} denotes conditional correlation of market noises between spot and futures markets that are the closest to maturity, cr_{122} denotes conditional correlation of market noises between spot and futures markets that are the second closest to maturity, and cr_{123}, cr_{124}, and cr_{125} are defined similarly. Seen from (14) and Figure 3, conditional variance of spot price and of futures price $\sigma_{s,t}^2$, $\sigma_{f,t}^2$ and conditional covariance of prices between spot and futures $\sigma_{sf,t}$ show higher time-varying trends; conditional correlation of market noises between spot and future markets exhibits a strongly time-varying trend. From Table 2, mean values of cr_{121}–cr_{125} are all negative, mean absolute values of cr_{121}–cr_{125} exhibit an increasing trend with

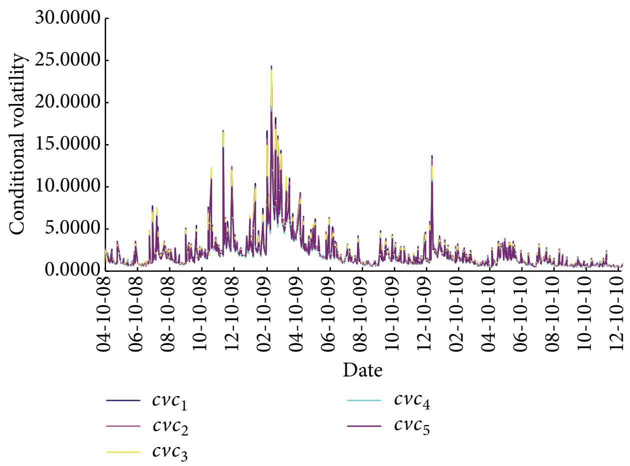

Figure 2: Conditional volatility with different maturities disturbed from futures market ($\times 10^{-4}$).

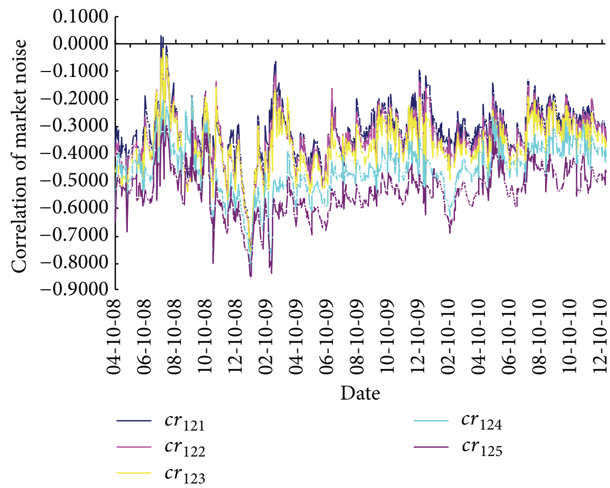

Figure 3: Conditional correlation of market noises between spot and futures.

Table 2: Statistical description of conditional correlation of market noises between spot and futures markets.

Correlation of market noises	Mean	Standard deviation	Maximum	Minimum
cr_{121}	−0.3222	0.0987	0.0321	−0.7470
cr_{122}	−0.3451	0.0960	−0.0291	−0.7596
cr_{123}	−0.3704	0.0958	−0.0131	−0.7662
cr_{124}	−0.4580	0.0937	−0.1914	−0.8179
cr_{125}	−0.5369	0.0865	−0.2759	−0.8539

an increase of time-to-maturity, and their standard deviations show a declining trend.

6.3. Conditional Correlation Estimation. In Figure 4, cr_1 denotes conditional correlation between spot and futures contracts that are the closest to maturity, cr_2 denotes conditional correlation between spot and futures contracts that

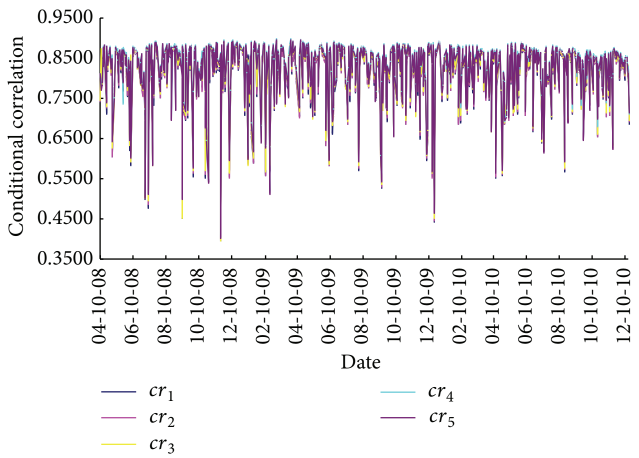

FIGURE 4: Conditional correlation coefficients between spot and futures with different maturities.

TABLE 3: Statistical description of conditional correlation coefficients between spot and futures with different maturities.

Conditional correlation	Mean	Standard deviation	Maximum	Minimum
cr_1	0.8142	0.0766	0.8916	0.3935
cr_2	0.8155	0.0764	0.8927	0.3997
cr_3	0.8193	0.0758	0.8951	0.3942
cr_4	0.8275	0.0738	0.8989	0.4062
cr_5	0.8235	0.0747	0.8962	0.4003

are the second closest to maturity, and cr_3, cr_4, and cr_5 are defined similarly. From Figure 4, optimal hedge ratios with different maturities exhibit strongly time-varying trends using ECM-GARCH (1, 1) model. Seen from Table 3, conditional correlation coefficients between spot and futures with different maturities show greater ranges from 0.39 to 0.90. Mean values of cr_1–cr_4 indicate an increasing trend with an increase of time-to-maturity, and their standard deviations show a decreasing trend.

7. Time-Varying Hedge Ratios and Hedging Effectiveness

7.1. Time-Varying Hedge Ratios. In Figure 5 and Table 4, hr_1 denotes optimal hedge ratio of futures contracts that are the closest to maturity, hr_2 denotes optimal hedge ratio of futures contracts that are the second closest to maturity, and hr_3, hr_4, and hr_5 are defined similarly. Optimal hedge ratios of futures contracts with different maturities exhibit significantly time-varying trends using ECM-GARCH (1, 1) model; they show greater ranges from 0.40 to 1.5. From Table 4, mean values of optimal hedge ratios exhibit an increasing trend with

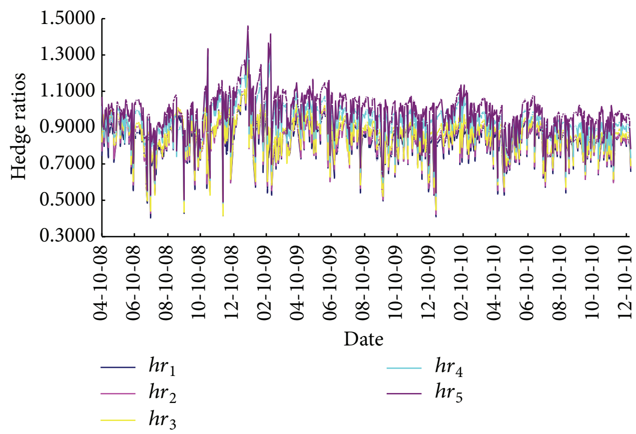

FIGURE 5: Time-varying hedge ratios of futures contracts with different maturities.

TABLE 4: Statistical description of time-varying hedge ratios of futures contracts with different maturities.

Hedge ratios	Mean	Standard deviation	Maximum	Minimum
hr_1	0.8279	0.1036	1.2421	0.4015
hr_2	0.8423	0.1045	1.2612	0.4168
hr_3	0.8619	0.1050	1.2716	0.4144
hr_4	0.9271	0.1097	1.3690	0.4792
hr_5	0.9776	0.1200	1.4596	0.4892

TABLE 5: Hedging effectiveness estimation of different-maturity futures contracts.

Futures	F_1	F_2	F_3	F_4	F_5
Hedging effectiveness	0.9080	0.9052	0.8992	0.8599	0.8549

an increase of time-to-maturity, and their standard deviations show an enlarging trend.

7.2. Hedging Effectiveness Estimation. Compared with the minimum variance of unhedged portfolio returns, Ederington [19] asserted that percentage reduction in the variance of hedged portfolio returns estimate hedging effectiveness (HE). Hedging portfolio returns are estimated using time-varying hedge ratios from ECM-GARCH model as follows (Table 5):

$$\mathrm{HE} = \frac{\mathrm{Var}(U_t) - \mathrm{Var}(H_t)}{\mathrm{Var}(U_t)}, \tag{15}$$

where $\mathrm{Var}(U_t)$ denotes the variance of unhedged assets portfolio returns and $\mathrm{Var}(H_t)$ denotes the variance of hedged assets portfolio returns. When futures prices for CO_2 emissions allowances completely decrease the risks of hedging portfolio returns, we can obtain $\mathrm{HE} = 1$ which indicates a 100% reduction in the variance of hedging portfolio returns, whereas we can obtain HE = 0 when hedging portfolio returns do not eliminate risk. Large number of HE shows better hedging performance between spot and futures with different maturities.

Compared with unhedged assets portfolio returns, market investors optimize hedge sizes between spot and futures with different maturities using previous optimal hedge ratios, and then the variance of hedging portfolio returns exhibits a significantly declining trend. The hedging risk of futures contracts that are the closest to maturity has an obvious 90.80% reduction, while the hedging risk of futures contracts that are the longest to maturity has an obvious 85.49% reduction. With an increase of time-to-maturity, hedging risks of futures contracts with different maturities exhibit a significantly declining trend.

8. Conclusion

Under departures from the cost-of-carry theory, conditional variance disturbed from futures market and conditional covariance between spot and futures of emissions allowances exhibit significantly time-varying trends, and market noises implied from futures market have significant impacts on conditional volatility. Conditional correlations of market noises between spot and futures markets are all negative, while conditional correlations between spot and futures are all positive; they exhibit obviously time-varying trends. Under departures from the cost-of-carry theory, optimal hedge ratios exhibit significantly time-varying trends using ECM-GARCH model, and time-varying hedge ratios show an enlarging trend with an increase of time-to-maturity. The conditional volatility of spot prices, conditional volatility disturbed from futures market, and conditional correlation coefficients of market noises implied from spot and futures markets have significant impacts on time-varying hedge ratios and hedging effectiveness. Market participants optimize assets portfolio sizes between spot and futures with different maturities using time-varying hedge ratios with departures from the cost-of-carry theory; the hedging risks of assets portfolio revenues have a significantly declining reduction, and they can achieve better hedging effectiveness.

Compared with financial markets and commodities markets such as gold, crude oil, and agriculture, current emissions allowances market has a more nascent and weaker market efficiency. Based on empirical results by Lafuente and Novales [14], Andani et al. [20] found that stock index futures markets in fully developed market exhibit a less liquid market, conditional volatility implied from futures market and conditional correlation of market noises exhibit lower fluctuated trends, and the discrepancy between theoretical and traded prices in fully mature financial markets does not represent a market noise factor that can be successfully exploited for hedging effectiveness. Some commodities markets have been significantly affected by specific market factors, such as agriculture market affected by extreme weather and specific geographic features and gold and crude oil commodities markets affected by production and transportation conditions. Emissions allowances market is quite different with general financial markets and commodities markets, emissions allowances prices are directly determined by the expected market scarcity induced by some specific market factors such as emissions reduction plan, government regulation policy, extreme weather deterioration, prices volatilities of different fossil energy, and emissions-reducing technology promotion and application. A good many complex markets factors exert greater market price shocks; however, price shock effectiveness has a tremendous difference in time and channel between emissions allowances spot and futures prices in the immature emissions allowances markets. Unexpected market information exhibits a different change speed for spot and futures prices; emissions allowances markets exhibit a greater lead-lag relationship between spot and futures. Based on the cost-of-carry theory, the theoretical and traded futures prices have a higher time-varying market deviation trends; their conditional volatility disturbed from futures market and conditional correlation coefficients of market noises implied from spot and futures markets are significantly greater than financial markets and commodities markets. An active hedging strategy involving spot and futures markets seems to be of interest in previous historical market information, conditional volatility disturbed from futures market, and conditional correlation of market noises between spot and futures when market participants attempt to achieve risk reduction. Market participants can flexibly adjust their assets portfolio policies between spot and futures and then achieve additional arbitrage returns under departures from cost-of-carry theory.

Effective macrocontrol and macroregulation are necessary to improve market efficiency in the emissions allowances markets. Macrocontrolling failure, uncertain decision, and inactive trading volumes have significant impacts on time-varying hedging effectiveness for emissions allowances. Government regulators should establish scientific emissions reduction plan and strict emissions quota allocation rules. Government should make consistent and systematic decision in the greenhouse emissions reduction, support regime-switching behaviors among different emissions markets, and strengthen international cooperation in the greenhouse emissions reduction. Government should present an international information network system of emissions trading markets, motor and check emissions reduction information. Market participants time capture demand and supply information, and then achieve fair, transparent, and symmetric emissions information. Emissions investors, hedgers, and arbitragers should be aware of risk reduction between spot and futures, regime switches, and threshold effects when attempting to forecast both spot and futures prices. An active hedging strategy involving spot and futures markets seems to be of interest in conditional volatility and correlation coefficients implied from futures markets. Our empirical pieces of evidence in this paper are helpful to more effectively reduce fluctuations risk of assets portfolio; market investors and hedgers should make optimally time-varying hedging policy to optimize hedging portfolio returns using time-varying hedge ratios under departures from cost-of-carry theory and then enhance the capabilities in risk reduction of assets portfolio for emissions allowances.

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