Constant vs. Time-varying Hedging Effectiveness Comparison for CO_2 Emissions Allowances: the Empirical Evidence from the EU ETS

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Abstract: - In recent years emissions allowances markets have become the most promising and quickly growing markets in the global commodities markets. In this paper, we estimate constant and time-varying optimal hedge ratios (OHR) and hedging effectiveness between spot and futures for CO_2 emissions allowances by choosing the two-step EG, ECM, ECM-GARCH, and modified ECM-GARCH techniques. The empirical results show that price series between spot and futures contracts with different maturities exhibit significant cointegration relation, the error corrections and previous price movement significantly affect the optimal hedge ratios, and the hedging effectiveness (HE) by using constant hedge ratios from the ECM method has slightly better than HE from the two-step EG method. The optimal hedge ratios from the ECM-GARCH and modified ECM-GARCH method exhibit strongly time-varying trend, and then the hedging effectiveness by using time-varying hedge ratios from the ECM-GARCH and modified ECM-GARCH method are significantly better than HE by constant hedge ratios. The hedging effectiveness from the modified ECM-GARCH methods is highest among the hedging portfolio returns by using the above four methods.

Key-Words: - Emissions allowances, hedge ratio, hedging effectiveness, ECM-GARCH, modified ECM-GARCH

1 Introduction

Greenhouse gas (GHS) emissions are an ever-creasing hot topic in the 21st century for the alarming phenomena of global warming and climate deterioration. Most of scientists and politicians generally accept emissions trading scheme is a cost-effective scheme. Since 2005, several emissions allowances markets have formally entered into oper -ation in the European Union emissions trading scheme (EU ETS). The right to emit a particular amount of CO_2 is given by a specific property in the EU ETS, it becomes a tradable and valuable commodity as same as the other physical commodities. In recent years emissions allowances have become the most promising and quickly growing markets in the global commodities markets. According to research report on state and trend of carbon market in 2011 by the World Bank, the total value of the global carbon markets grew 6% to US $144 billion (or €103 billion) until 2010, its trade volume attained 8.7 billion tons CO_2. Emissions allowances markets will become the largest commodity markets in the futures.

Several empirical results show that spot and futures prices for CO_2 emissions allowances are shown to contain a dynamic behaviour [1-4].Benz and Truck (2006) propose emissions allowances prices are directly determined by the expected market scarcity which is induced by the current demand and supply [1]. Seifert et al (2008), Benz and truck (2009) propose dynamics behavior of CO_2

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trend, accordingly spot and futures prices series exhibit non-stationary feature [1-5]. The prices spreads between spot and futures for CO_2 emissions allowances are determined by their dynamic relationship. In general, high correlation in returns of two underlying assets is important for short-run price relationships, but high correlation in assets returns does not necessarily imply high co-integration in prices. Cointegration is a technique to measure long-term dynamic equilibrium relationship between two underlying assets prices generated by historical market information and behaviours feature.

3.1 The Estimation of Constant Hedge Ratio

Based on the hedging theories, naive hedging strategy suggests that to minimize exposure, a bona fide hedger who hold long position CO_2 spot should sell a unit of CO_2 futures at time *t*, and buy the CO_2 futures back when he sell a unit of CO_2 spot. We consider a bona fide hedger can hold the assets portfolio of c_s units long position spot and c_f units short position futures, and the assets portfolio returns ΔV_h is equal to

$$\Delta V_h = c_s \Delta s_t - c_f \Delta f_t \tag{1}$$

Where s_t, f_t is the nature logarithms in price both spot and futures for CO_2 emissions allowances at time t, $\Delta s_t = s_t - s_{t-1}, \Delta f_t = f_t - f_{t-1}$. Accordingly assets portfolio risk is equal to as follows:

$$\operatorname{var}(\Delta V_h) = c_s^2 \operatorname{var}(\Delta s_t) + c_f^2 \operatorname{var}(\Delta f_t) - 2 c_s c_f \operatorname{cov}(\Delta s_t, \Delta f_t) \tag{2}$$

We attain the minimum variance of hedge ratio by minimizing the risk of hedge portfolio [13].

$$h^* = \frac{c_f}{c_s} = \frac{\operatorname{cov}(\Delta s_t, \Delta f_t)}{\operatorname{var}(\Delta f_t)} \tag{3}$$

3.2 Constant Hedging Ratio Using Cointegra -tion

Alexander (1999) proposes when spreads are mean-reverting, prices are cointegrated, and attain optimal hedging policy of Spot-futures financial assets using cointegration theory [14]. Engle and Granger (1987) propose two-step examine technique, EG method is to perform an ordinary least squares regression, and then test the residuals for stationarity [12].

$$\begin{aligned} \Delta s_t &= a + b \Delta f_t + \xi_t \\ \xi_t - \xi_{t-1} &= \omega \xi_{t-1} + \mu_t \end{aligned} \tag{4}$$

Where ξ_t is the residual, μ_t is a Gaussian disturbance. Engle and Granger (1987) demonstrate that the error term ξ_t must be mean reverting if two underlying prices exhibit cointegration [12]. A conventional approach to estimate h* relies upon the simple linear regression method. We apply the daily settlement price to estimate the relationship b in spot-futures prices for emissions allowances. The estimated coefficient is the estimated optimal hedge ratio. Thereby the optimal hedge ratio from two-step EG model remains constant.

Since the price series both spot and futures for emissions allowances are non-stable, If prices series both spot and futures exhibit cointegrated relationship, the estimated coefficient b is biased, thereby the optimal hedge ratio is not optimal. The two-step EG approach ignores many historical market information variables. Notably previous prices movements in the spot and futures CO_2 markets and the co-integrated relations in prices between spot and futures contracts may affect optimal hedge ratio. Based on the cointegration theory, Peng and Ye (2007), Fang and Chen (2008) proposes the optimal hedge ratio by using error correction model (ECM) [15-16]. ECM is a dynamic model, which is based on correlations in returns of two underlying assets, ECM reflects that short-term deviation is away from the long-term equilibrium. Accordingly ECM considers non-stationary in prices between spot and futures, long-run equilibrium, short-run dynamics. ECM takes the form:

$$\Delta s_t = \alpha_s + \sum_{i=1}^{m} \beta_{si} \Delta s_{t-i} + \sum_{j-1}^{n} \gamma_{sj} \Delta f_{t-j} + \theta_s z_{t-1} + \varepsilon_{st} \tag{5}$$

$$\Delta f_t = \alpha_f + \sum_{i=1}^{m} \beta_{si} \Delta s_{t-i} + \sum_{j=1}^{n} \gamma_{fj} \Delta f_{t-j} + \theta_f z_{t-1} + \varepsilon_{ft} \tag{6}$$

Where Δ denotes the time series difference of each variable, $z_t = f_t - s_t$ denotes the cointegration vector, and the lags lengths and coefficients are determined by ordinary least squares regression. If z is large and positive, this will have a negative effect on Δs, for $\theta_s < 0$ and z will decrease, the effect on Δf is positive for $\theta_f > 0$, and f_t will increase, and errors are corrected in this way. When spot-futures prices for emissions allowances are cointegrated, the error-correction model will capture dynamic correlations and causalities between two prices returns. The above ECM can also be written as the following forms [15-16]:

$$\Delta s_t = \alpha + h\Delta f_t + \sum_{i=1}^{m}\beta_i \Delta s_{t-i} + \sum_{j=1}^{n}\gamma_i \Delta f_{t-j} + \theta z_{t-1} + \varepsilon_t \quad (7)$$

3.3 Empirical Results of Constant Hedge Ratio

Shown in the following table 2, the residuals statistical value of ADF test in the two-step EG model is far less than the critical value at the confidence level 99%, they indicate the residuals from EG model exhibit steady. Price series between spot and five futures contracts exhibit cointegrated relations. Seen from the following table 2, we propose fitting goodness R^2 and z-statistic values are all larger, accordingly the fitting results from the EG and ECM are well. Obviously we can see constant hedge ratios from the ECM model are all bigger than hedge ratios from the EG model, the estimated coefficients of error corrections vector are significant, these empirical results show the error corrections affect the optimal hedge ratio, and previous prices movement both spot and futures for emissions allowances significantly affect the optimal hedge ratio. The hedge ratio of long-maturity futures is bigger than the hedge ratio of short-maturity futures.

Table 2 The empirical results of constant hedge ratio from the EG and ECM model

Cointegration test		F_1	F_2	F_3
	h^*	0.9716	0.9939	1.0082
	z	90.83	102.49	95.51
EG	R^2	0.923	0.938	0.929
	ξ ADF	-22.257	-26.006	-24.181
	h^*	0.9869	0.9996	1.0107
	z	119.41	119.89	104.35
ECM	R^2	0.955	0.955	0.942
Cointegration test		F_4	F_5	
	h^*	1.0667	1.1252	
	z	69.89	68.04	
EG	R^2	0.876	0.870	
	ξ ADF	-22.960	-22.420	
	h^*	1.0688	1.1265	
	z	71.74	69.07	
ECM	R^2	0.884	0.876	

Note: 1.EG, ECM denotes two-step test of Engle and Granger and error correction model, h^* is constant hedge ratio.

2. $\xi_t = \Delta s_t - (a + b\Delta f_t)$, ξ -ADF denotes the statistic values of ADF test for the residuals. Under the confidence level 99%, 95%, 90%, the critical values of ADF test with intercept are -3.4396, -2.8655, -2.5689.

3.The above table2 reports estimated coefficients by the following ECM equation:

$$\Delta s_t = \alpha + h\Delta f_t + \beta_1 \Delta s_{t-1} + \gamma_1 \Delta f_{t-1} + \theta z_{t-1} + \varepsilon_t$$

4 Time-varying Optimal Hedge Ratio Using Cointegration

In the above two cointegration tests, ADF and ECM are assumed the residuals have constant variances and covariances. Bollerslev (1990), Kroner and Sultan (1993), Lien, Tse and Tsui (2002), Lien and Yang (2008) estimate optimally time-varying hedge ratio by using the BGARCH model [17-20]. Kroner and Sultan (1993), Koutmos and Pericli (1998, 1999), Lien and Tse (1999), Peng and Ye (2007) propose time-varying hedging by using the bivariate error-correction GARCH model[15,21-23]. Since cointegration can measure long-run co-movement in prices, hedging methodologies using cointegration theory for CO_2 emissions allowances may be more effective in the long term.

4.1 The Estimation of Time-varying Hedge Ratio

If spot and futures prices for CO_2 emissions allowances both change by the same amount, the hedgers will not change net position, and the hedge ratios are constant. In the realistic emissions allowances markets, spot and futures prices do not always move at the same speed, the wise hedger can adjust hedging net position by the information set at the time *t-1*, accordingly the hedge ratios are dynamic. We consider a bona fide hedger within a one-period framework from time *t-1* to time *t* reducing the risk exposure, the hedger assumes short positions for CO_2 futures contract. Based on the information set ϕ_{t-1}, the hedgers have non-tradable spot position Q at time *t-1* and sell X futures contracts, let $h_{t-1} = X/Q$. The returns of hedging portfolio in the period *(t-1, t)* are equal to

$$R_{ht} = \Delta s_t - h_{t-1}\Delta f_t \quad (8)$$

Where h_{t-1} is hedge ratio at the time *t-1*, the risk of hedging portfolio is measured by the conditional variance at the information available set ϕ_{t-1} . The returns of variance are equal to

$$\operatorname{var}(R_{ht}|\phi_{t-1}) = \operatorname{var}(\Delta s_t|\phi_{t-1}) + h_{t-1}^2 \operatorname{var}(\Delta f_t|\phi_{t-1}) - 2h_{t-1}\operatorname{cov}(\Delta s_t, \Delta f_t|\phi_{t-1}) \quad (9)$$

The hedgers choose the optimal hedge ratio h* to minimize the variance risk given by the $\operatorname{var}(R_{ht}|\phi_{t-1})$.

$$h^* = \frac{\operatorname{cov}(\Delta s_t, \Delta f_t|\phi_{t-1})}{\operatorname{var}(\Delta f_t|\phi_{t-1})} \quad (10)$$

Where cov(.) is the covariance operator. When spot and futures markets generate new information, the optimal hedge ratios show time-varying trend.

4.2 Dynamic Optimal Hedge Ratio Using Co-integration

The early research results show spot and futures prices for CO_2 emissions allowances are directly determined by the expected market scarcity, which is induced by the change of emissions regulation policy, extreme weather, energy price, abatement technology progress etc[1-2][9]. Benz and truck (2009) provide spot volatility behaviour for emissions allowances is of dynamics trend by GARCH model in the pilot phase. In realistic CO_2 emissions allowances markets, the conditional covariance matrix in spot-futures prices show actually time-varying behaviours. Accordingly optimal hedge ratios exhibit time-varying trend rather than constant trend. The following section, the hedgers can attain optimally time-varying hedge ratios and hedging efficiency by using ECM-GARCH and modified ECM-BGARCH model.

We can estimate optimally dynamic hedge ratios by the bivariate GARCH incorporated the error correction term. Thereby the bivariate ECM-GARCH structure look as follows [13-14,16, 19-20].

$$\Delta s_t = c_s + d_{s1}\Delta f +_t d_{s2}(\Delta s_{t-1} - \Delta f_{t-1}) + \zeta_{st} \quad (11)$$

$$\Delta f_t = c_f + d_{f1}\Delta s + d_{f2}(\Delta s_{t-1} - \Delta f_{t-1}) + \zeta_{ft} \quad (12)$$

$$\sigma_{st}^2 = \delta_s + \sum_{i=1}^{p} a_{si}\zeta_{s(t-i)}^2 + \sum_{j=1}^{q} b_{sj}\sigma_{s(t-j)}^2 \quad (13)$$

$$\sigma_{ft}^2 = \delta_f + \sum_{i=1}^{p} a_{fi}\zeta_{f(t-i)}^2 + \sum_{j=1}^{q} b_{fj}\sigma_{f(t-j)}^2 \quad (14)$$

$$\sigma_{sft} = \rho\sqrt{\sigma_{st} \times \sigma_{ft}} \quad (15)$$

Where ρ is the correlation coefficient between two underlying assets, which is assumed to be constant.

When spot and futures markets for CO_2 emissions allowances are mature, the basis risks in spot-futures prices are smaller, then the error correction terms denote basis risks are feasible, and they indicate cointegrated relations in spot-futures prices. However CO_2 emissions allowances markets are of emerging markets, the basis risks are larger, estimated optimal hedge ratios have the bigger bias and affect hedging efficiency by using error correction term induced basis risk. We develop the general modified ECM-GARCH structure.

$$\Delta s_t = c_s + d_s\Delta f_t + \sum_{i=1}^{m} u_{si}\Delta s_{t-i} + \sum_{j=1}^{n} v_{sj}\Delta f_{t-j} + w_s\xi_{t-1} + \varsigma_{st} \quad (16)$$

$$\Delta f_t = c_f + d_f\Delta s_t + \sum_{i=1}^{m} u_{fi}\Delta s_{t-i} + \sum_{j=1}^{n} v_{fi}\Delta f_{t-j} + w_f\xi_{t-1} + \varsigma_{ft} \quad (17)$$

Where the residual terms $(\varsigma_{st}, \varsigma_{ft})^T$ follow BGARCH process, the residual term $\xi_{t-1} = \Delta s_t - (a + b\Delta f_t)$. In the above equation (16-17), the bivariate GARCH may be incorporated into the EC model, we can obtain optimal hedge ratios from the ECM- GARCH and modified ECM –GARCH model. In each case, one-period hedge ratio h^* is equal to $\frac{\sigma_{sf}^2}{\sigma_f^2}$, which is time-varying trend.

4.3 Empirical Results of Dynamic Hedge Ratio

Due to nonlinearity caused by the GARCH effects, the optimally dynamic hedge ratios change with the change of hedging time series. To calculate the dynamic hedge ratio over multiple days, we rely upon iterations from equation (11) to equation (17). A bivariate ECM-GARCH is used to estimating time-varying hedge ratios by the error correction terms. The modified ECM-GARCH is incorporated into the previous price series and the residual term from two-step EG method.

Shown in the following table 3 and 4, except intercept term, z-statistic value of estimated coefficients from the ECM-GARCH(1,1) and modified ECM- GARCH(1,1) model are all larger, their probabilities are all extremely small. Accordingly estimated parameters coefficients are significant at the significant level 99%. Based on estimated coefficients in the table 3 and 4, we can attain the optimally dynamic hedge ratios by the ECM-GARCH (1,1) and modified ECM-GARCH (1,1) methods.

Shown from figure 2 to figure 6, the optimal hedge ratios from ECM-GARCH (1,1) and modified ECM-GARCH(1,1) are all time-varying and their volatilities of optimal hedge ratios are of fierce jump. In the following table 5, we propose statistical description of dynamic hedge ratio from the above two model. As we have seen from the table 5, the means of OHR from the ECM-GARCH(1,1) are larger than those from modified ECM-GARCH(1,1) between spot and futures F_1, F_3, F_4, however means of OHR from ECM- GARCH(1,1) are less than those from modified ECM-GARCH(1,1) between spot and futures F_2, F_5. Standard deviations of hr_1, hr_4 are bigger than them of mhr_1, mhr_4, however standard deviations of hr_2, hr_3, hr_5 are less than them of mhr_2, mhr_3, mhr_5.

Table3 Estimated parameters coefficients from the ECM-GARCH(1,1)

coefficients	F_1	F_2	F_3
δ_s	2.84e-7	7.21e-8	4.78e-8
δ_f	2.53e-7	8.09E-8	6.78e-8
a_{s1}	0.150***	0.101***	0.076***
	(8.06)	(8.66)	(7.63)
a_{f1}	0.143***	0.103***	0.088***
	(8.71)	(8.70)	(8.22)
b_{s1}	0.843***	0.897***	0.923***
	(48.44)	(74.59)	(89.74)
b_{f1}	0.850***	0.895***	0.910
	(48.71)	(73.17)	(82.50)
coefficient	F_4	F_5	
δ_s	4.70e-8	2.18e-7	
δ_f	2.46e-8	1.60e-7	
a_{s1}	0.064***	0.081***	
	(12.24)	(14.66)	
a_{f1}	0.048***	0.069***	
	(17.56)	(13.76)	
b_{s1}	0.935***	0.916***	
	(175.40)	(160.45)	
b_{f1}	0.952***	0.928***	
	(343.11)	(172.67)	

Table 4 Estimated parameter coefficients from the modified ECM-GARCH(1,1)

coefficients	F_1	F_2	F_3
δ_s	1.92e-7	9.20e-8	1.14e-7
δ_f	1.72e-7	1.08e-7	1.48e-7
a_{s1}	0.175***	0.138***	0.121***
	(9.65)	(9.50)	(8.83)
a_{f1}	0.169***	0.148***	0.136***
	(10.01)	(9.27)	(8.80)
b_{s1}	0.818***	0.858***	0.876***
	(41.88)	(55.88)	(60.43)
b_{f1}	0.825***	0.848***	0.859***
	(45.56)	(50.15)	(51.88)
coefficients	F_4	F_5	
δ_s	8.80e-8	4.21e-6	
δ_f	8.43e-8	3.36e-6	
a_{s1}	0.085***	0.485***	
	(13.83)	(15.50)	
a_{f1}	0.077***	0.492***	
	(13.47)	(14.76)	
b_{s1}	0.915***	0.470***	
	(147.16)	(13.05)	
b_{f1}	0.921***	0.453***	
	(155.43)	(12.00)	

*Note: F_1-F_5 denote the EUA futures contracts for emissions allowances with the varying maturity going from December 2009 to December 2014. *** denote significant at the significant level 99%, the number in the parentheses is z-statistic values.*

Table5 Statistical description of optimally time-varying hedge ratio

futures	*mean*	*std.dev*	*maximun*	*minimum*
$F_1(hr_1)$	0.962	0.039	1.125	0.833
$F_1(mhr_1)$	0.961	0.036	1.148	0.835
$F_2(hr_1)$	0.981	0.035	1.122	0.863
$F_2(mhr_1)$	0.983	0.037	1.119	0.878
$F_3(hr_1)$	1.005	0.047	1.142	0.872
$F_3(mhr_1)$	1.002	0.051	1.159	0.856
$F_4(hr_1)$	1.013	0.101	2.306	0.856
$F_4(mhr_1)$	1.008	0.057	1.313	0.842
$F_5(hr_1)$	1.069	0.065	1.479	0.916
$F_5(mhr_1)$	1.108	0.139	1.905	0.755

Note: $hr_{1\text{-}5}$, $mhr_{1\text{-}5}$ denote optimally dynamic hedge ratio from ECM-GARCH(1,1) and modified ECM-GARCH(1,1) model between spot and futures contracts with the varying maturity going from December 2009 to December 2014.

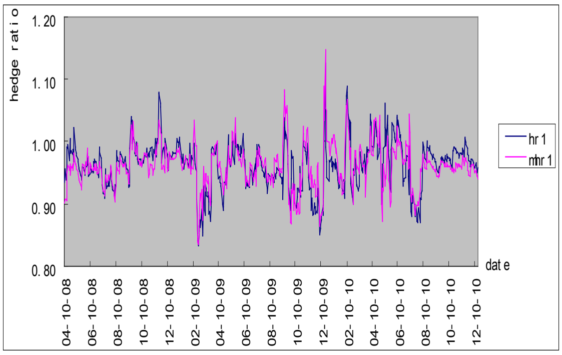

Figure 2: Dynamic hedge ratio between spot and futures F_1