Convenience Yields and Options Value of Exchanging different-maturity Futures Contracts Implied from Emissions Allowances Futures Market

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Abstract: - Our results find that futures contracts with different maturities for emissions allowances exhibit a significant cointegration relationship by using two-step EG model, similar market information has a convergent effect on prices spreads of futures contracts with different maturities. Convenience yields implied from the futures markets exhibit a significant options property. Convenience yields are call or put options, based on extending exchange options pricing model, market participants flexibly optimize assets portfolio sizes between the nearby and distant futures contracts using the options property of convenience yields for emissions allowances, and then they can achieve excess market investment revenues.

Key-Words: - emissions allowances, cointegration, futures prices spreads, convenience yields, different-maturity futures, options property, investment revenues

1 Introduction

Most of global scientists and politicians generally believe that emissions trading scheme is a cost-effective market scheme in order to prevent climax deterioration and control greenhouses gas (GHG) emissions reduction. In European Unions emissions allowances markets, Spot, forwards, futures, options and swaps are important financial tools of emissions allowances for market participants to enhance assets portfolio returns and strengthen risk reduction management. According to research report on state and trend of carbon market in 2011 by the World Bank, the total value of global carbon markets grew 6% to US $144 billion until 2010, emissions allowances markets will become the largest commodities markets in the futures [1].

Spot and futures prices of emissions allowances depend crucially on expected market scarcity induced by demand and supply in the emissions allowances markets, and many complex factors such as national GHG emissions reduction planning and quota allocation scheme, low-carbon technology promotion and application, fossil fuels prices volatility, energy consumption structure, energy allocation efficiency and extreme temperature changes have significant impacts on emissions allowances market scarcity [2-3]. Several empirical results show that spot and futures prices exhibit significantly time-varying trends. Spot prices of emissions allowances exhibit strongly time-varying trends (see Seifert, Homburg and Wagner, 2008; Benz and Truck, 2009). Seifert et al. (2008) present a tractable stochastic equilibrium model reflecting stylized features of the EU ETS, an adequate CO_2 prices process should exhibit a time- and price-dependent volatility structure [4]. Benz and Truck (2009) analyze the short-term spot price behavior of CO_2 emission allowances of the new EU ETS, and their results strongly support the adequacy of the models capturing characteristics like skewness, excess kurtosis and in particular different phases of volatility behavior in the returns [3]. Daskalakis, Psychoyios and Markellos (2009) suggest that uncertain banking-borrowing prohibition of emission allowances between distinct phases of the EU ETS has significant implications in terms of futures pricing, and develop an empirical framework for the pricing and hedging of intra-phase and inter-phase futures and options in the Pilot and Kyoto phase [5]. Marliese and Michael (2009) examine that futures contracts lead the price discovery process of CO_2 emission allowances, EUA futures can therefore be of crucial importance for all participants in the emission allowances market through facilitating price discovery and offering means of hedging CO_2-related risks [6].In the Pilot phase, immature emissions allowances markets induce lower market efficiency, while market efficiency has better recovery signs in the Kyoto phase [7]. In immature emissions allowances, favorable and unfavorable market information indicates greater market overreaction and market prices shocks in the Pilot phase, market volatilities in prices both spot and futures don't follow a mean-reversion process, they exhibit significantly divergent and unpredictable trends [8]. Chang and Wang et al. (2012) present a new N-factor affine term structure model for CO_2 futures price and estimate parameters in the new affine model using the Kalman filter technique, and their empirical results show that CO_2 futures prices follow significant mean-reversion process, two-factor and three-factor model can accurately describe the term structure of CO_2 futures price than one-factor model in the Kyoto phase [9]. Chevallier (2010) analyzes the modelling of risk premia in CO_2 allowances spot and futures prices, risk premia in CO_2 spot and futures prices features positive time-varying, and have a positive relationship between risk premia and the variance/skewness of CO_2 spot prices [10]. Arouri et al. (2012) uses VAR and STR-EGARCH model to examine the dynamic relationships between the EU Emission Allowances (EUA) spot and futures prices during Phase II, their main findings show that emission allowances spot and futures returns are asymmetrically and nonlinearly related [11]. Gorenflo (2013) analyze the pricing and lead-lag relationship between spot and futures prices of CO_2 emission allowances in the EU emission trading scheme [12]. Koop and Tole (2013) propose jointly model the spot and future prices both EUA and CER using flexible multivariate time series methods, their results show little evidence of volatility spillovers or of Granger causality among EUA, CER and macroeconomic events [13]. Charles et al. (2013) examine that futures contracts are found to be cointegrated with spot prices and interest rates for several maturities in three main European markets (BlueNext, EEX and ECX), According to individual and joint tests, the cost-of-carry model is rejected for all maturities and CO_2 markets, these signs exhibit market inefficiency and may bring arbitrage opportunities in the emission allowances market [14]. The above empirical results verify spot prices, futures prices and their volatility exhibit obvious time-varying trends, optimize different assets portfolio sizes and bring market arbitrage opportunities in immaturity emission allowances markets.

Many early empirical results verify convenience yields are call or put options, market participants optimize different assets portfolio sizes using the convenience yields, and then gain excess market options value. When commodity storage cost is equal to zero, commodity expected prices are higher than spot prices, holding spot commodity can attain additional profit, and then price difference between spot and futures is a call options [15]. Commodities convenience yields are call options, underlying assets, time-to-maturity, and prices volatility have significant impacts on options value of convenience yields [16]. Kocagil (2004) verify options value of commodities convenience yields, his results indicate that marginal cost and spot prices have significant effects on options value of commodities convenience yields [17]. Lin and Duan (2007) propose that commodities convenience yields are negatively related to inventory level of underlying crude oil and positively related to interest rates, convenience yields may explain price spread between WTI crude oil and Brent crude oil [18]. Chang and Wang (2011) present that the convenience yields of emissions allowances have significantly positive relationship with spot prices, their volatility and previous convenience yields, convenience yields have significantly negative relationship with futures prices [19]. Chang et al. (2012) propose a general model of options valuation for different-maturity futures contracts under the term structure of stochastic multi-factors, their empirical results exhibit that stochastic multi-factors have significant impacts on options valuation for CO_2 futures contracts with different maturities, and estimate the theoretical futures options valuation using historical market information set [20]. Chen and Zhang (2009) introduce carbon tax as an emission-reduction policy, and study the feasibility of reducing greenhouse gas emission implementing carbon tax in China [21]. Ma and Cheng (2010) discuss the relationships among public finance, energy saving and emission reduction based on current energy and resources pressure [22]. Xu (2011) shows the main factors affecting Chinese carbon emission have output scale, industrial structure and energy consumption structure [23]. Yao and Yang (2012) analyze the basic principles and decisions of the carbon tax idea，and point out two determinants in constituting the optimal carbon tax [24]. Fan and Li (2013) build a dynamic optimization model in the environment constraints，solve the optimal carbon tax rate，and calculate it based on Chinese panel data [25]. Thalfeldt and Valtin (2010) propose the strategic environmental assessment of the CO_2 and SO_2 emissions of electricity production scenarios using the Long range Energy Alternatives Planning System (LEAP) software [26]. Taking Chinese industrial structure and energy consumption in each industry into account, Zhou and Mi (2009) calculate energy consumption and CO2 emissions from 2010 to 2030, If clear energy account for 20% of total energy consumption, CO_2 emissions can be reduced 1.95 billion tons in 2030 [27]. Ahmad et al. (2013) develop and deploy methods for obtaining real-world, on-road micro-scaled measurements of vehicle emissions to estimate the pollutants [28]. Neri (2012) discuss that partial knowledge and full knowledge learning scenario are relevant to the modeling of financial time serial and estimate the robustness of a modelling system for financial time series [29]. Neri (2012) reproduces the process of value formation by computationally simulating the community of agents-investors, compare our system's performances and provide empirical data about the effectiveness of different computational techniques [30]. Accordingly the commodities convenience yields are potential benefits implied from the commodities markets, convenience yields are call options, and then market participants can gain additional market arbitrage revenues using the options property of convenience yields [15-18]. Emissions allowances markets are similar as the general commodities markets, early empirical results that convenience yields of emissions allowances can reflect prices spreads between the near and distant futures contracts, market participants accurately estimate futures and options prices using the options value of convenience yields.

Emissions allowances markets are emerging financial markets. Emissions allowances prices are one of the most effective market signs, accurately reflect market scarcity induced by supply and demand, and they are a cost-effective economical way to allocate environment resources and achieve GHG emissions reduction. In the weak-effective emissions allowances markets, different-maturity futures prices have greater upward risk and downward risk trends, significant market risks bring market investors about a tremendous uncertainty and unpredictability in assets portfolio returns between the nearby and distant futures contracts for emissions allowances.

The main innovations of this paper is that we capture the options property of convenience yields implied from the emissions allowances futures market, and options value of futures contracts between the nearby and distant futures contracts using the convenience yields. These empirical results are helpful for explaining prices spreads between the near and distant futures contracts. They are also helpful for accurately optimizing assets portfolio sizes among futures contracts with different maturities and achieving the greater market arbitrage revenues through exchanging futures contracts.

The remainder of our paper is organized as follows. Section 2 describes the sourcing of data samples. Section 3 proposes cointegration tests. Section 4 analyses options property of futures contracts with different maturities. Section 5 presents the statistical results of convenience yields implied from the futures market. Section 6 examines options property of convenience yields. Section 7 estimates and discusses options value of exchanging futures contracts between the nearby and distant futures contracts. Section 8 provides a brief conclusion.

2 Data Source

European-wide emissions allowances markets have existed two phases: the trial phase (2005-2007) and the Kyoto phase (2008-2012). In this paper, we select that data samples of different-maturity futures contracts are from the most liquid and largest CO_2 futures ICE exchange platform in the EU ETS. One European Union emission 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 CO_2 equivalent. We choose daily settlement price for EUA futures contracts with different delivery dates from December 2010 to December 2014. Since the trading of futures contracts with vintages December 2013 and December 2014 were started on April 8, 2008. Considered the continuity and availability of numerical samples, we select that data samples cover the period from April 8, 2008 to December 20, 2010 in the Kyoto phase. In the figure 1, F_1 denotes the EUA futures contracts that are the closest to maturity, F_2 denotes the second closest to maturity, and F_3, F_4, F_5 are defined similarly. From the figure 1, we obviously observe that CO_2 futures prices with different maturities exhibit similarly time-varying trends throughout the sample period. The free-risk interest rates are 12-month Euribor.

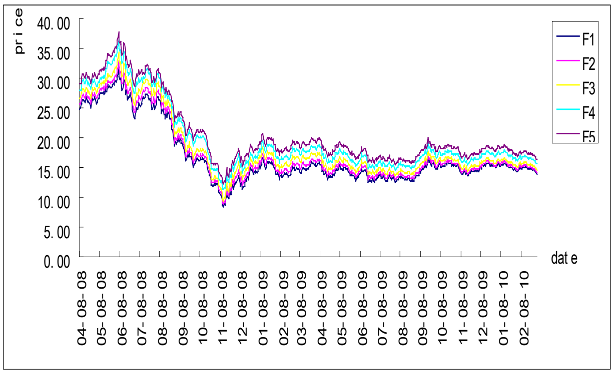

Fig.1 Futures prices with different maturities for emissions allowances

3 Cointegration Test

Fama (1970) presents futures market prices can reflect all available market information in an efficient futures market [31]. In the immature emissions allowances markets, many complex factors induce greater market overreaction, unexpected market information enlarge expected market scarcity. Futures prices with different maturities cannot increase or decline at the same speed and channel in the short term, the theoretical and actual futures prices exhibit time-varying deviation trends. Market participants can capture convenience yields by holding short-term or long-term futures contracts, and then market exerts some arbitrage opportunities. Market participants can gain excess assets portfolio revenues through optimizing futures assets policies. If futures prices with different maturities for emissions allowances exhibit a strong correlation, they show similar convergent trends. Accordingly market participants can adjust futures assets portfolio policies using the convenience yields implied from the futures markets, increase assets portfolio returns and market risks reduction.

Assumed emissions allowances futures market is an efficient market, market participants are unbiased, risk-neutral and rational decision-makers, futures contracts with different maturities can freely trade in the emissions allowances market. Long-run maturity futures prices can be expressed by expected futures prices with short-run maturity at time t.

$$F_{t,T_2} = E(F_{t+1,T_1} | I_t)$$

(1)

Here F_{t+1,T_1}, F_{t,T_2} denote the nearby futures contract for maturity T_1 at time $t+1$, and the distant futures contract for maturity T_2 at time t, I_t denotes all available market information set at time t. In the actual futures market, market participants may be biased and risk-neutral decision-makers, emissions allowances futures market exists obvious market risk premium.

$$F_{t,T_2} = E(F_{t+1,T_2} | I_t) + u_t$$

(2)

Here u_t denotes market risk premium. Market risk premium show a time-varying trend in the actual futures market. If futures prices with different maturities for emissions allowances follow Augmented Dickey-Fuller (ADF) unit root process, futures prices of emissions allowances exhibit significant long-memory and persistent market volatility. Two-step EG model examine that futures prices between the nearby and distant futures contacts exhibit a significant cointegration relationship, the residual reject null hypothesis, these residual series follow a stable process. We present two-step EG model in order to verify cointegration relationship between F_{t+1,T_1} and F_{t,T_2} [32].

$$F_{t+1,T_1} = g_0 + g_1 F_{t,T_2} + v_{t+1}$$

$$\Delta v_t = \eta_0 v_{t-1} + \sum_{i=1}^{m} \eta_i \Delta v_{t-i} + \zeta_t$$

(3)

Equation (3) explains the nearby and distant futures markets for emissions allowances exhibit significant market liquidity, change speeds of futures prices with different maturities have different change trends. If futures prices with different maturities exist obvious cointegration relationship, similar market information hasn't an enlarging impact on the difference of futures prices between the nearby and distant futures contracts.

Table 1 Statistical result of futures prices with different maturities using two-step EG model

coefficients	$F_{1,t+1}$ & $F_{2,t}$	$F_{1,t+1}$ & $F_{3,t}$
g_0	-0.037***	-0.116***
	(-3.54)	(-8.80)
g_1	1.0003***	1.0111***
	(270.82)	(220.28)
R^2	0.991	0.986
$ADF(\varsigma_t)$	-20.8333	-11.1273
coefficients	$F_{1,t+1}$ & $F_{4,t}$	$F_{1,t+1}$ & $F_{5,t}$
g_0	-0.297***	-0.476***
	(-17.29)	(-23.89)
g_1	1.0476***	1.0886***
	(180.43)	(164.13)

R^2	0.979	0.975
$ADF(\varsigma_t)$	-8.3244	-7.3057
coefficients	$F_{2,t+1}$ & F_{3t}	$F_{2,t+1}$ & $F_{4,t}$
g_0	-0.069***	-0.251***
	(-6.36)	(-17.57)
g_1	1.0069***	1.0442***
	(267.82)	(215.88)
R^2	0.990	0.985
$ADF(\varsigma_t)$	-20.4331	-10.6785
coefficients	$F_{2,t+1}$ & $F_{5,t}$	$F_{3,t+1}$ & $F_{4,t}$
g_0	-0.433***	-0.168***
	(-26.10)	(-13.31)
g_1	1.0858***	1.0322***
	(197.01)	(242.27)
R^2	0.982	0.988
$ADF(\varsigma_t)$	-9.2522	-12.7053
coefficients	$F_{3,t+1}$ & $F_{5,t}$	$F_{4,t+1}$ & $F_{5,t}$
g_0	-0.350***	-0.160***
	(-24.91)	(-15.43)
g_1	1.0743***	1.0359***
	(230.13)	(294.85)
R^2	0.987	0.992
$ADF(\varsigma_t)$	-11.5253	-21.4752

Note: $ADF(\varsigma_t)$ denotes t - value using ADF model, after Lag n=2, the critical values of ADF test with intercept are -2.5683, -1.9413, -1.6164 at the confidence 99%, 95%, 90% level.

Seen from the table 1, t -values show higher values, futures prices between the nearby and distant futures contracts have a significant correlation at the confidence 99% level. The t-values of the residual using ADF method are all less than the critical value -2.5683 at the significance 99% level, these empirical results show that futures prices between the nearby and distant futures contracts exhibit a significant cointegration relationship. The related coefficients of futures prices with different maturities have an increasing trend with an increase of time-to-maturity.

4 Options Property of Futures Contracts with Different Maturities

Futures spread arbitrage is to buy one commodity futures contracts while selling other futures contracts of similar commodity in the futures assets investment operation. In general, the futures contracts arbitraged using futures spread have a strong correlation relationship, and futures prices with different maturities have similar convergent trends. In the competitive emissions allowances market, assumed emissions allowances markets exist no transaction costs, no arbitrage behavior and no storage costs, S_t denotes spot prices of emissions allowances, F_{t,T_1} denotes market price of futures contracts for maturity T_1 at time t , r is the continuously compounded risk-free interest rate. Based on cost-of-carry theory, the shorter-maturity futures prices are equal to [33-34]

$$F_{t,T_1} = S_t e^{(r-cy)(T_1-t)} \tag{4}$$

Similarly, market prices of futures contract for maturity T_2 at time t are equal to

$$F_{t,T_2} = S_t e^{(r-cy)(T_2-t)} \tag{5}$$

Based on equation (4) and (5)

$$F_{t,T_2} = F_{t,T_1} e^{(r-cy)(T_2-T_1)} \tag{6}$$

When $F_{t,T_2} > F_{t,T_1} e^{r(T_2-T_1)}$, the convenience yields implied from the futures markets are negative. Spot prices of emissions allowances quickly decline with an increase of unexpected market supply, unexpected market information has a higher impact on the nearby futures prices than the distant futures prices, inclining speeds of nearby futures prices are higher than distant futures prices. Market participants can buy distant futures contracts at time t while selling nearby futures contracts for emissions allowances. When $F_{t,T_2} < F_{t,T_1} e^{r(T_2-T_1)}$, the convenience yields implied from the futures market are positive. Unexpected market demand information push up greater market scarcity, unexpected increasing speed of nearby futures prices is higher than distant futures prices, and then holding nearby futures contracts for emissions allowances can capture greater convenience yields. Market participants can buy nearby futures contracts at time t while selling distant futures contracts for emissions allowances.

5 Convenience Yields Implied from the Emissions Futures Markets

Based on cost-of-carry theory, commodity convenience yields are revenues measure of holding certain storage level in an uncertain market condition. Convenience yields are significantly related with commodity production, storage level, transportation cost and other related costs. Convenience yields are implied revenues or excess risk premium to reply expected changes of emissions allowances prices. Unexpected quantity changes between supply and demand push up emissions allowances market scarcity and overreaction, thereby spot and futures prices exhibit strong market volatility. Market overreaction and prices unpredictability bring about greater market scarcity, futures prices with different maturities have different changing speeds, market investors can achieve excess convenience yields implied from the futures market.

Based on futures prices and market interest rate, Gibson and Schwartz (1990) [35], Bessemblinder (1995) [36], Liu and Tang (2011) [37] presents commodity convenience yields implied from the futures market can be expressed by

$$cy(t,T_1,T_2)=r-\frac{1}{T-t}\ln(\frac{F_{t,T_2}}{S_t})$$
$$\approx r-\frac{\ln F_{t,T_2}-\ln F_{t,T_1}}{T_2-T_1}$$
(7)

In the figure 2, 3, 4, cy_{12} denotes convenience yields between futures contracts for maturity T_1 and futures contracts for maturity T_2, cy_{13} denotes convenience yields between futures contracts for maturity T_1 and futures contracts for maturity T_3, $cy_{14}-cy_{45}$ are defined similarly. In figure 2, 3, and 4, Convenience yields implied from the emissions allowances futures market exhibit obvious time-varying trends, convenience yields have strong market volatility and significant clustering effects.

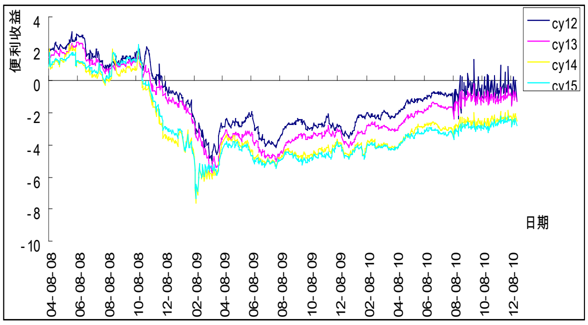

Fig 2 Convenience yields implied from the futures markets (F_1-F_5)

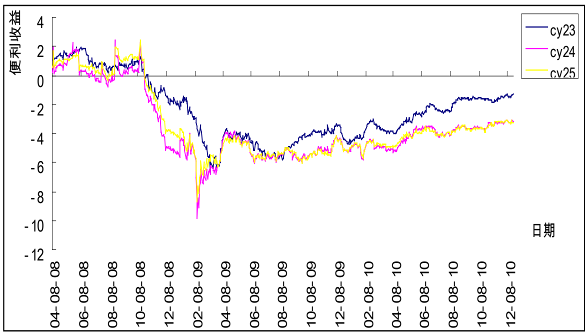

Fig 3 Convenience yields implied from the futures markets (F_2-F_5)

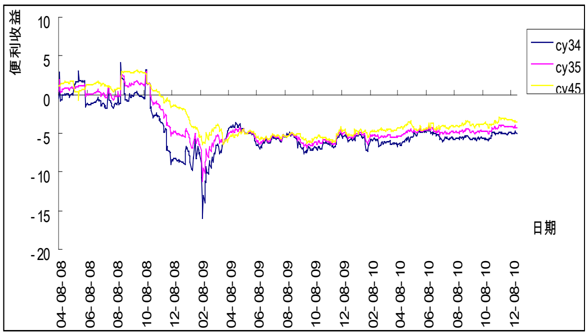

Fig 4 Convenience yields implied from the futures markets (F_3-F_5, F_4-F_5)

From the table 2, the t-values of convenience yields implied from the futures markets are greater than the critical values -1.6164 at the confidence 90% level using ADF without intercept model, these results show that the convenience yields exhibit non-stationary trends. The t-values under first-different ADF model are less than the critical value -2.5683 at the confidence 99% level, thereby the first difference of convenience yields exhibit stationary trends.

Table 2 ADF test results of convenience yields implied the futures markets

variable	cy series	1-difference
cy_{12}	-1.5645	-30.4827***
cy_{13}	-0.8205	-25.2780***
cy_{13}	-0.6701	-31.7568***
cy_{15}	-0.4913	-29.8647***
cy_{23}	-0.6144	-31.2840***
cy_{24}	-0.6970	-29.3470***
cy_{25}	-0.5297	-27.6674***
cy_{34}	-1.0390	-29.1243***
cy_{35}	-0.6508	-27.0911***
cy_{45}	-0.5311	-28.4410***

*Note: the statistical values in the table 2 are t-values using ADF model without intercept. The critical values are -2.5683, -1.9413 and -1.6164 at the confidence 99%, 95% and 90%, Lag n=2. ***, **, * denote the confidence 99%, 95% and 90% level.*

6 Options Property Test of Convenience Yields with Different Maturities

Positive convenience yields are call options, holding the nearby futures contracts can capture implied convenience yields, while negative convenience yields are put options, holding the distant futures contracts can capture implied convenience yields. Unexpected market shock has a different impact on futures prices with different maturities, market participants adjust futures assets portfolio sizes through unexpected volatility of futures prices, and then achieve excess arbitrage incomes. In the actual emissions allowances market, prices spreads of futures contracts with different maturities contain convenience yields implied from the futures markets. Based on equation (6), we can gain the following equation (8)

$$\ln F_{t,T_2} = \ln F_{t+1,T_1} + r(T_2 - T_1) - cy(T_2 - T_1)$$
(8)

From the equation (8), we can achieve the following equation (9)

$$IAB_t = r(T_2 - T_1) - cy(T_2 - T_1)$$
$$= \ln F_{t,T_2} - \ln F_{t+1,T_1}$$
(9)

From the equation (9), convenience yields implied from the futures markets have significant impacts on prices spreads of futures contracts with different maturities. Prices spreads of futures contracts have enlarging trends with an decline of convenience yields, while prices spreads of futures contracts have shrinking trends with an increase of convenience yields. When unexpected market volatility of futures contracts exhibit a stationary trend, arbitrage revenues are disappeared with an adjustment of assets portfolio sizes among different futures contracts. Assumed longer-maturity futures prices discounted by constant risk-free interest rate, $f_{t,T_2} = F_{t,T_2} e^{-r(T_2-t)/365}$. We propose the following hypothesis.

Hypothesis 1: convenience yields of emissions allowances are negatively related with prices spreads between the distant and nearby futures contracts, while they are positively related with prices spreads between the nearby and distant futures contracts.

Hypothesis 2: when convenience yields implied from emissions allowances futures markets are positive, prices spreads between the nearby and discounted distant futures contracts are positively related with convenience yields. When convenience yields implied from the futures market are negative, prices spreads between the discounted distant and nearby futures contracts are negatively related with convenience yields.

When the convenience yields implied from the futures markets are positive, we present the following equation (10) and (11)

$$\ln F_{t+1,T_1} - \ln F_{t,T_2} = A_0 + A_1 cy_t + \varepsilon_t$$
(10)

$$\ln F_{t+1,T_1} - \ln f_{t,T_2} = B_0 + B_1 cy_t + B_2 \varepsilon_t + \xi_t$$
(11)

When the convenience yields implied from the futures markets are negative, we present the following equation (12) and (13)

$$\ln F_{t,T_2} - \ln F_{t+1,T_1} = A_0 + A_1 cy_t + \varepsilon_t$$
(12)

$$\ln f_{t,T_2} - \ln F_{t+1,T_1} = B_0 + B_1 cy_t + B_2 \varepsilon_t + \xi_t$$
(13)

Where $\ln F_{t+1,T_1} - \ln F_{t,T_2}, \ln F_{t,T_2} - \ln F_{t+1,T_1}$ denote prices spreads between the nearby and distant futures contracts, and prices spreads between the distant and nearby futures contracts. $\ln F_{t+1,T_1} - \ln f_{t,T_2}, \ln f_{t,T_2} - \ln F_{t+1,T_1}$ denote prices spreads between the nearby and discounted distant futures contracts, and prices spreads between the discounted distant and nearby futures contracts. Based on the above hypothesis, we present empirical results from equation (10) to equation (13).

From the table 3, convenience yields are significantly positive related with prices spreads between the nearby and distant futures contracts. The related coefficients A_1 between convenience yields and prices spreads of futures contracts are 1.5974, 2.7935, 3.9008, 4.8601, they have an increasing trend with an increase of time-to-maturity.

Table 3 Regression results of equation (10) and (11) ($cy > 0$)

coefficient	F_1 & F_2	F_1 & F_3	F_1 & F_4
A_0	-0.0635***	-0.1163***	-0.1660***
	(-11.39)	(-22.31)	(-50.37)
A_1	1.5974***	2.7935***	3.9008***

	(5.28)	(7.88)	(12.59)
R^2	0.169	0.312	0.436
B_0	0.1083***	0.2242***	0.3460***
	(53.15)	(63.14)	(111.64)
B_1	1.4442***	2.3265***	2.1486***
	(13.04)	(9.64)	(7.38)
B_2	0.9224***	0.8044***	0.7031***
	(29.50)	(13.80)	(8.74)
R^2	0.884	0.677	0.592
coefficients	F_1 & F_5	F_2 & F_3	F_2 & F_4
A_0	-0.2197***	-0.0596***	-0.1078***
	(-45.98)	(-13.67)	(-51.35)
A_1	4.8601***	1.6401***	2.4807***
	(12.00)	(4.19)	(9.87)
R^2	0.413	0.114	0.418
B_0	0.4541***	0.1150***	0.2368***
	(79.58)	(71.90)	(171.37)
B_1	2.8352***	1.3358***	1.3834***
	(5.87)	(9.30)	(8.37)
B_2	0.4527***	0.9256***	0.8295***
	(4.42)	(29.40)	(14.70)
R^2	0.585	0.876	0.679
coefficient	F_2 & F_5	F_3 & F_4	F_3 & F_5
A_0	-0.1627***	-0.0530***	-0.1061***
	(-47.50)	(-31.24)	(-43.37)
A_1	3.3692***	1.1272***	2.0705***
	(10.13)	(8.19)	(9.36)
R^2	0.430	0.330	0.392
B_0	0.3516***	0.1210***	0.2411***
	(104.76)	(200.20)	(133.58)
B_1	2.0725***	0.8169***	1.5430***
	(6.30)	(16.67)	(9.45)
B_2	0.6064***	0.9273***	0.7613***
	(7.15)	(30.36)	(12.03)
R^2	0.518	0.899	0.634
coefficient	F_4 & F_5		
A_0	-0.0504***		
	(-14.79)		
A_1	0.8418***		
	(4.71)		
R^2	0.140		
B_0	0.2862***		
	(106.42)		
B_1	1.2199***		
	(8.64)		
B_2	0.8311***		
	(12.29)		
R^2	0.626		

Note; 1. convenience yields implied from the futures markets are positive, $cy > 0$ *, data samples cover the period form April 8, 2008 to October 21,2008.*

*2. *** , ** , * denote the confidence 99% , 95% and 90% level, the number in the parentheses is t statistic values.*

Table 4 Regression results of equation (12) and (13) ($cy < 0$)

coefficients	F_1 & F_2	F_1 & F_3	F_1 & F_4
A_0	0.0208***	0.0393***	0.0440***
	(9.66)	(14.37)	(9.43)
A_1	-0.7410***	-1.6911***	-3.0572***
	(-8.05)	(-18.52)	(-26.01)
R^2	0.111	0.397	0.565
B_0	-0.0240***	-0.0550***	-0.0766***
	(-21.99)	(-22.13)	(-13.55)
B_1	-0.9510***	-2.1417***	-2.9301***
	(-20.39)	(-25.82)	(-20.59)
B_2	0.8745***	0.5900***	0.0927*
	(39.39)	(14.83)	(1.75)
R^2	0.791	0.630	0.610
coefficients	F_1 & F_5	F_2 & F_3	F_2 & F_4
A_0	0.0689***	0.0244***	0.0198***
	(12.21)	(7.68)	(3.88)
A_1	-3.8135***	-0.8022***	-2.2351***
	(-27.75)	(-10.14)	(-21.31)
R^2	0.596	0.165	0.465
B_0	-0.1256***	-0.0271***	-0.0456***
	(-17.24)	(-17.83)	(-8.86)
B_1	-4.4399***	-1.0405***	-1.8361***
	(-25.03)	(-25.24)	(-17.34)
B_2	0.3274***	0.8704***	0.4831***
	(5.79)	(38.11)	(10.92)
R^2	0.605	0.801	0.546
coefficients	F_2 & F_5	F_3 & F_4	F_3 & F_5
A_0	0.0468***	-0.0036***	0.0141**
	(7.75)	(-0.83)	(2.29)
A_1	-2.9878***	-1.3175***	-2.3197***
	(-23.50)	(-19.05)	(-20.17)
R^2	0.515	0.410	0.438
B_0	-0.0983***	-0.0191***	-0.0623***
	(-13.00)	(-7.87)	(-9.39)
B_1	-3.3515***	-0.8727***	-2.1352***
	(-21.03)	(-22.44)	(-17.22)
B_2	0.0054***	0.8713***	0.4130***
	(0.10)	(35.36)	(8.74)
R^2	0.560	0.771	0.517
coefficients	F_4 & F_5		
A_0	0.0257***		
	(5.98)		
A_1	-0.7763***		
	(-8.28)		
R^2	0.116		
B_0	-0.0522***		
	(-21.80)		

B_1	-1.5456***
	(-29.62)
B_2	0.8365***
	(34.31)
R^2	0.798

Note: 1. convenience yields implied from the futures markets are negative, $cy < 0$.

2. data samples cover the period form December 4, 2008 to December 20, 2010.

The related coefficients are significant at the confidence 99% level, and t-values indicate larger values, the regression results support hypothesis 1. The related coefficients B_1 between convenience yields $cy_{12} - cy_{14}$ and discounted prices spreads of futures contracts are 1.4442, 2.3265, 2.1486, 2.8352, these coefficients are all positive. The related coefficients between discounted prices spreads and the residual term are 0.9224, 0.8044, 0.7031 and 0.4527, these coefficients have a declining trend with an increase of time-to-maturity. The t-values of related coefficients B_1, B_2 indicate greater values, all R^2-values have significant increasing trends and the related coefficients are significant at the confidence 99% level, these results support hypothesis 2. Other convenience yields with different maturities are obviously positive correlation relationship with prices spreads of futures contracts, and convenience yields implied from the futures markets exhibit a significant options property, these regression results support hypothesis 1 and 2.

Seen from the table 4, when convenience yields implied from the futures markets are negative, $cy < 0$, the related coefficients A_1 between convenience yields $cy_{12} - cy_{15}$ and prices spreads of futures contracts are -0.7410, -1.6911, -3.0572 and -3.8135,which are all negative, and these coefficients exhibit a higher significance at the confidence 99% level, and t-values are greater, these results support hypothesis 1. The related coefficients B_1 between convenience yields $cy_{12} - cy_{15}$ and discounted prices spreads of futures contracts are -0.9510, -2.1417, -2.9301 and -4.4399, these coefficients are all negative. Absolute values of these coefficients A_1, B_1 show an increasing trend with an increase of time-to-maturity. The related coefficients B_2 between discounted prices spreads and convenience yields are 0.8745, 0.5900, 0.0927 and 0.3274, these coefficients exhibit a higher significance at the confidence 99% level. These empirical results support hypothesis 2. The above empirical results show the convenience yields implied from the futures contracts have a significant options property, the regression results support hypothesis 1 and 2.

7 Arbitrage Revenues of Convenience Yields for Futures Contracts with Different Maturities

Based on Brenna (1986) [38], Molonas and Thomadakis (1997) [16] estimation, convenience yields of futures contracts with different maturities are equal to the prices difference between the nearby futures and distant futures discounted by constant interest rate.

$$CY_t = F_{t,T_1} - F_{t,T_2} e^{-r(T_2 - T_1)} \tag{14}$$

Here CY_t denotes convenience yields implied from the futures markets. Market participants can optimize assets portfolio policies of futures contracts with different maturities using the options property of convenience yields. Assumed the futures prices follow a geometric Brownian process.

$$\begin{aligned} dF_{t,T_1} &= \mu_n F_{t,T_1} dt + \sigma_n F_{t,T_1} dz_n \\ dF_{t,T_2} &= \mu_d F_{t,T_2} dt + \sigma_d F_{t,T_1} dz_d \end{aligned} \tag{15}$$

Here μ_n, μ_d denote the instantaneous returns in price for the nearby and distant futures contracts, σ_n, σ_d denote the volatility in price for the nearby and distant futures contracts, dz_n, dz_d denote the increment of a standard Wiener process for the nearby and distant futures contracts, and $dz_n dz_d = \rho_{nd} dt$, where ρ_{nd} denotes the related coefficient between the nearby and distant futures contracts. When the convenience yields implied from the futures markets are positive, convenience yields are call options, market participants buy nearby futures contracts while selling distant futures contracts.

$$OCY = MAX(F_{t,T_1} - F_{t,T_2} e^{-r(T_2 - T_1)}, 0) \tag{16}$$

In the emissions allowances markets, market participants can hold different futures assets and optimize assets portfolio policies of futures contracts with different maturities using the changes both futures prices spread and convenience yields. Assumed exchange costs of futures assets are equal to zero, and then options values of convenience yields are equal to exchange options value between the nearby and discounted distant futures contracts. Based on Poitras (1998) [39], Lin and Duan (2007) [18], we propose a new extending exchange options pricing model, options values of convenience yields are equal to

$$V_{CY}=F_{t,T_1}N(d_1)-F_{t,T_2}e^{-r(T_2-T_1)}N(d_2)$$

$$d_1=\frac{\dfrac{E(\ln F_{t,T_1})}{E(\ln F_{t,T_2}e^{-r(T_2-T_1)})}+\dfrac{\sigma_F^2\tau}{2}}{\sigma_F\sqrt{\tau}} \qquad (17)$$

$$d_2=d_1-\sigma_F\sqrt{\tau}$$

$$\sigma_F=\sigma_n^2+\sigma_d^2-2\rho_{nd}\sigma_n\sigma_d$$

Here $E(\ln F_{t,T_1}),E(\ln F_{t,T_2}e^{-r(T_2-T_1)})$ denote the mean of the logarithm of the nearby futures prices and discounted distant futures prices, $N(.)$ denotes the cumulative probability function, τ denotes the exchange period between the nearby and distant futures contracts. The price volatility σ_n^2,σ_d^2 both the nearby and distant futures contracts, their related coefficient ρ_{nd} are all constant in the assets exchange period. When the convenience yields implied from the futures markets are negative, market participants buy the distant futures contracts while selling the nearby futures contracts, and then convenience yields are put options, market participant can attain excess options value through optimizing different futures assets policies.

Table 5 options value of convenience yields through exchanging futures contracts with different maturities (F_1 and F_2,F_3,F_4,F_5)

coefficients	$cy_{12}>0$	$cy_{12}<0$
Period interval	2008.4.8-2008.12.3	2008.12.4-2010.12.20
τ	0.6548	2.0438
ρ	0.9990	0.9931
σ_F^2	0.0349	0.0265
Ex policy	F_2exF_1	F_1exF_2
$N(d_1)$	0.5712	0.5805
$N(d_2)$	0.5113	0.4881
V_{CY}	1.7353	1.7337
Ex policy	F_1exF_2	F_2exF_1
$N(d_1)$	0.4887	0.5119
$N(d_2)$	0.4288	0.4195
V_{CY}	1.2574	1.3114
ΔV_{CY}	0.4779	0.4223
coefficients	$cy_{13}>0$	$cy_{13}<0$
Period interval	2008.4.8-2008-11.6	2008.11.7-2010.12.20
τ	0.5808	2.1178
ρ	0.9931	0.9739
σ_F^2	0.1088	0.1302
Ex policy	F_3exF_1	F_1exF_3
$N(d_1)$	0.5913	0.6418
$N(d_2)$	0.4918	0.4357
V_{CY}	2.8324	4.1705
Ex policy	F_1exF_3	F_3exF_1
$N(d_1)$	0.5082	0.5642
$N(d_2)$	0.4087	0.3582
V_{CY}	2.1039	4.0195
ΔV_{CY}	0.7286	0.1610
coefficients	$cy_{14}>0$	$cy_{14}<0$
Period interval	2008.4.8-2008.10.21	2008.10.22-2010.12.20
τ	0.5370	2.1616
ρ	0.9590	0.9621
σ_F^2	0.4217	0.2857
Ex policy	F_4exF_1	F_1exF_4
$N(d_1)$	0.6159	0.7034
$N(d_2)$	0.4282	0.4007
V_{CY}	4.9237	6.6084
Ex policy	F_1exF_4	F_4exF_1
$N(d_1)$	0.5718	0.5993
$N(d_2)$	0.3841	0.2966
V_{CY}	4.3313	6.3590
ΔV_{CY}	0.5924	0.2494
coefficients	$cy_{15}>0$	$cy_{15}<0$
Period interval	2008.4.8-2008.10.23	2008.10.24-2010.12.20
τ	0.5425	2.1562
ρ	0.9607	0.9461
σ_F^2	0.5406	0.3798
Ex policy	F_5exF_1	F_1exF_5
$N(d_1)$	0.6370	0.7332
$N(d_2)$	0.4243	0.3888
V_{CY}	5.6702	7.0831
Ex policy	F_1exF_5	F_5exF_1
$N(d_1)$	0.5757	0.6112
$N(d_2)$	0.3630	0.2668
V_{CY}	4.7772	6.9480
ΔV_{CY}	0.8930	0.1351

Table 6 options value of convenience yields through exchanging futures contracts with different maturities (F_2 and F_3,F_4,F_5)

coefficients	$cy_{23}>0$	$cy_{23}<0$
Period interval	2008.4.8-2008.10.21	2008.10.30-2010.12.20
τ	0.5370	2.1397
ρ	0.9967	0.9929
σ_F^2	0.0264	0.0430
Ex policy	F_3exF_2	F_2exF_3

$N(d_1)$	0.5578	0.6030
$N(d_2)$	0.5105	0.4832
V_{CY}	1.3439	2.4268
Ex policy	F_2exF_3	F_3exF_2
$N(d_1)$	0.4895	0.5168
$N(d_2)$	0.4422	0.3970
V_{CY}	1.0810	2.3289
ΔV_{CY}	0.2629	0.0979
coefficients	$cy_{24} > 0$	$cy_{24} < 0$
Period interval	2008.4.8-2008.7.2	2008.10.22-2010.12.20
τ	0.2329	2.1616
ρ	0.9834	0.9806
σ_F^2	0.3302	0.1597
Ex policy	F_4exF_2	F_2exF_4
$N(d_1)$	0.5770	0.6741
$N(d_2)$	0.4669	0.4457
V_{CY}	2.8726	5.3587
Ex policy	F_2exF_4	F_4exF_2
$N(d_1)$	0.5331	0.5543
$N(d_2)$	0.4230	0.3259
V_{CY}	2.7525	4.9255
ΔV_{CY}	0.1201	0.4332
coefficients	$cy_{25} > 0$	$cy_{25} < 0$
Period interval	2008.4.8-2008.10.21	2008.10.22-2010.12.20
τ	0.5370	2.1616
ρ	0.9730	0.9723
σ_F^2	0.4235	0.2271
Ex policy	F_5exF_2	F_2exF_5
$N(d_1)$	0.6154	0.7063
$N(d_2)$	0.4273	0.4372
V_{CY}	4.9997	6.0894
Ex policy	F_2exF_5	F_5exF_2
$N(d_1)$	0.5727	0.5628
$N(d_2)$	0.3846	0.2937
V_{CY}	4.5644	5.9218
ΔV_{CY}	0.4353	0.1676

Table 7 options value of convenience yields through exchanging futures contracts with different maturities (F_3 and F_4, F_5 , F_4 and F_5)

coefficients	$cy_{34} > 0$	$cy_{34} < 0$
Period interval	08.5.6-08.6.3	08.10.22-10.12.20
τ	0.0767	2.1616
ρ	0.9478	0.9902
σ_F^2	0.0417	0.0787
Ex policy	F_4exF_3	F_3exF_4
$N(d_1)$	0.6098	0.6371
$N(d_2)$	0.5879	0.4754
V_{CY}	0.6406	4.0437
Ex policy	F_3exF_4	F_4exF_3
$N(d_1)$	0.4121	0.5246
$N(d_2)$	0.3902	0.3629
V_{CY}	0.6088	3.6380
ΔV_{CY}	0.0318	0.4057
coefficients	$cy_{35} > 0$	$cy_{35} < 0$
Period interval	08.4.8-08.7.7	08.10.22-10.12.20
τ	0.2466	2.1616
ρ	0.9912	0.9874
σ_F^2	0.2892	0.1051
Ex policy	F_5exF_3	F_3exF_5
$N(d_1)$	0.5722	0.6744
$N(d_2)$	0.4661	0.4902
V_{CY}	2.9012	4.3945
Ex policy	F_3exF_5	F_5exF_3
$N(d_1)$	0.5339	0.5098
$N(d_2)$	0.4278	0.3256
V_{CY}	2.7204	4.2682
ΔV_{CY}	0.1808	0.1263
coefficients	$cy_{45} > 0$	$cy_{45} < 0$
Period interval	08.4.8-08.11.10	08.11.13-10.12.20
τ	0.5918	2.1014
ρ	0.9965	0.9964
σ_F^2	0.0741	0.0198
Ex policy	F_5exF_4	F_4exF_5
$N(d_1)$	0.5714	0.6240
$N(d_2)$	0.4883	0.5446
V_{CY}	2.4976	1.7978
Ex policy	F_4exF_5	F_5exF_4
$N(d_1)$	0.5117	0.4554
$N(d_2)$	0.4286	0.3760
V_{CY}	2.1509	1.7739
ΔV_{CY}	0.3467	0.0239

Note: 1.In the table 5, 6, 7 F_2exF_1 denotes that the distant F_2 futures contract exchange the nearby F_1 futures contract, F_1exF_2 the nearby F_1 futures contract exchange the distant F_2 futures contract, the others variables are defined similarly.

2. ΔV_{CY} denote that market participants gain excess investment incomes using the options property of convenience yields.

Table 5 show options value of exchanging assets between the nearby futures contract F_1 and distant futures contract F_2, F_3, F_4, F_5 using the convenience yields. Take the nearby futures F_1 and distant futures F_2 for an example. In the exchange period from April 8, 2008 to December 3, 2008, the convenience yields implied from the futures markets are positive, $cy_{12} > 0$, the convenience yields are call options. Market participants buy the distant F_2 futures contract while selling the nearby F_1 futures contract, and then they can gain 1.2574 € options value per ton through exchanging futures assets. Market participants find that convenience yields exhibit significant options property, they make the contrary decision to buy the nearby F_1 futures contract while selling the distant F_2 futures contract, and then they can attain 1.7353€ options value per ton using the options property of convenience yields. Thereby market participants optimize assets portfolio policies of futures contracts with different maturities through using the convenience yields implied from the futures markets, they can achieve excess 0.4779€ investment revenue per ton. In the exchange period from December 4, 2008 to December 20, 2010, the convenience yields implied from the futures markets are negative, $cy_{12} < 0$, convenience yields are put options. Market participants buy the nearby F_1 futures contract while selling the distant F_2 futures contract, and then they can attain 1.3114€ options value per ton through exchanging futures assets. Market participants make the contrary investment policy to buy the distant F_2 futures contract while selling the nearby F_1 futures contract, and then they can gain 1.7337€ options value per ton through using the options property of convenience yields. Accordingly, when convenience yields implied from the futures markets are negative, market participants can optimize assets portfolio policies through using the convenience yields implied from the futures markets, and then they can achieve additional 0.4223€ investment revenue per ton. Based on similar assets exchange policies, when the convenience yields implied from the futures markets are positive, market participants hold the nearby F_1 futures contact substituting the distant F_3, F_4, F_5 futures contracts, and then they can gain 0.7286€, 0.5924€, 0.8930€ investment revenues per ton using the convenience yields. When the convenience yields implied from the futures markets are negative, market participants hold the distant F_3, F_4, F_5 futures contracts substituting the nearby F_1 futures contact, and then they can gain 0.1610€, 0.2494€, 0.1351€ investment revenues per ton using the convenience yields.

Seen from the table 6, when the convenience yields are positive, market participants hold the nearby F_2 futures contracts substituting the distant F_3, F_4, F_5 futures contracts, and they can capture excess 0.2629€, 0.1201€ and 0.4353€ investment revenues per ton through using the options property of convenience yields. When the convenience yields are negative, market participants hold the distant F_3, F_4, F_5 futures contracts substituting the nearby F_2 futures contracts, and they can gain excess 0.0979€, 0.4332€ and 0.1676€ investment revenues per ton through using the options property of convenience yields. Seen from the table 7, based on similar exchange assets policies, market participants adjust assets portfolio policies between the nearby and distant futures contracts through using the options property of convenience yields, and then they can achieve additional investment incomes. In brief, when the convenience yields implied from the futures markets are positive, convenience yields are call options, market participants buy the nearby futures contracts while selling the distant futures contracts. When the convenience yields implied from the futures markets are negative, convenience yields are put options, market participants buy the distant futures contracts while selling the nearby futures contracts, these assets portfolio policies can gain excess investment revenues through exchanging futures assets with different maturities.

8 Conclusion

The convenience yields implied from the futures markets are equal to prices difference between the nearby and distant futures contracts. We propose the empirical results on the options property of convenience yields and options value of exchanging futures assets using the options property of convenience yields.

Our empirical results show that the nearby and distant futures contracts exhibit a significant cointegration relationship using two-step EG model, and similar market information have a convergent impact on market prices for different futures markets. Convenience yields implied from the futures markets show time-varying trends and significantly clustering effects. Convenience yields implied from the futures markets exhibit a significant correlation with prices spreads between the nearby and distant futures contracts, and convenience yields have a significant options property. Based on extending exchange options pricing model, our empirical results show that when convenience yields implied from the futures markets are positive, convenience yields are call options. Based on the options property of convenience yields for emissions allowances, market participants make an effective policies to buy the nearby futures contracts while selling the distant futures contracts. When the convenience yields implied from the futures markets are negative, convenience yields are put options. Market participants make an effective policies to buy the distant futures contracts while selling the nearby futures contracts. Market participants optimize assets portfolio policies of futures contracts through using the convenience yields implied from the futures markets, and then they can achieve excess investment revenues.

In the actual emissions allowances markets, convenience yields implied from the futures markets exhibit time-varying trends. Firstly our empirical results show that futures prices with different maturities exhibit similar convergent trends, and they have significant cointegration relationship. Secondly we confirm the options property of convenience yields from the theoretical and empirical analysis. Thirdly, based on extending exchange options pricing model, we compare different assets portfolio policies through exchanging futures assets between the nearby and distant futures contracts discounted by risk-free interest rate, our empirical results verify that market participants can make more scientific assets portfolio policies using the options property of convenience yields, and then achieve excess market arbitrage revenues through exchanging futures assets.

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