Convenience yields and arbitrage revenues of emission allowances between spot and futures

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Abstract: - Based on the data samples using EUA spot and futures in the ICE and BLUENEXT exchange platform in the European Union emissions trading scheme (EU ETS), this paper propose the market behavior of convenience yields and examine the options feature of convenience yields for emission allowances. When the convenience yields of emission allowances are positive, the convenience yields are positively related with the spread between spot expected value and futures price of emission allowances. When the convenience yields of emission allowances are negative, the absolute value of convenience yields are positively related with the spread between futures price and spot expected value of emissions allowances, and then the convenience yields of emission allowance have a significant options property. Our empirical evidence show that when the convenience yields are call or put options, market participants can flexibly adjust portfolio policies of emission allowances assets, based on the extension of options pricing model of assets exchange, and then achieve extra market arbitrage revenues through exchanging emission allowances assets between spot and futures.

Key-Words: - emission allowances; convenience yields; options property; assets exchange; arbitrage revenue

1 Introduction

Most of scientists and politicians generally believe that emissions trading scheme is a cost-effective market scheme in order to prevent climax change and control greenhouses gas (GHG) emissions reduction. In recent years, emissions allowances markets have become the most promising and quickly growing markets in the global commodities markets. Spot, forwards, futures, options and swaps are important financial tools for market participants to increase 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 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.

Brennan(1986) [1], Heinkel et al.(1990) [2] propose that commodities convenience yields are negatively related with inventory level, the convenience yields reduce with an increase of inventory level. When commodity storage cost is equal to zero, the expected price of commodity is greater than spot spice, and then holding commodity spot can attain excess profitability. If spot-sale commodity is as futures contract of commodity, the difference between expected price of spot-holding and spot-sale commodity is a call option. Milonas and Thomadakis (1997) present the empirical evidence on the storage commodities of soybeans, corn, wheat and copper, their results show that the convenience yield is a call options, its options value are related with underlying assets, the maturity of futures contract and strike price [3]. When futures price is very sensitive to convenience yields, the options-call feature of convenience yields cannot ignore. Kacogil (2004) consider that the convenience yields are call options, the value of commodity convenience yield is significantly related with marginal cost and spot price [4]. Lin and Duan (2007) examine that supply and demand of commodity market and convenience yields exhibit obviously seasonal market volatility, the convenience yields are negatively related with inventory level, are positively related with market interest rate, the convenience yield value can explain the price difference among different commodities markets [5].

Spot and futures prices of emission allowances depend crucially on expected market scarcity

induced by demand and supply total quantity in the emission allowances markets, and many complex factors such as GHG emission reduction planning and regulations policy, low-technology promotion and application, energy prices volatility, energy efficiency and extreme temperature changes have significant impacts on emissions allowances market scarcity [6-7].Several empirical results show that spot and futures prices for CO_2 emission allowances are shown to contain a dynamic behavior [6-9].Benz and Truck (2006) propose that emission allowances prices are directly determined by the expected market scarcity which is induced by the current demand and supply [6]. Seifert et al (2008), Benz and truck (2009) propose dynamics behavior of CO_2 spot price [7-8]. Seifert et al (2008) find CO_2 spot prices do not follow any seasonal patterns, they exhibit a time- and price-dependent volatility structure in the pilot phrase. Benz and truck (2009) present the short-term spot price behavior of carbon dioxide (CO2) emission allowances of the new EU-wide CO2 emissions trading system. Chang and Wang et al. (2012) propose a new N-factor affine term structure model for CO2 futures price and their empirical results show that CO2 futures prices and convenience yields follow significant mean-reversion process [9]. Daskalakis, Psychoyios and Markellos (2009) find that banking-borrowing regulation prohibition has a significant impact on spot and futures prices, market participants can achieve market arbitrage incomes through optimizing assets portfolio policy between futures and options markets in the Pilot and Kyoto phase [10]. In the Pilot phase, immature emission allowances markets induce lower market efficiency, while market efficiency has better recovery signs in the Kyoto phase [11]. Favorable and unfavorable market information exhibits greater market overreaction induced by lower market efficiency in the Pilot phase, and spot and futures prices, market volatility for emission allowances don't follow a mean-reversion process, they exhibit obvious divergent and unpredictable trends [12]. Chang and Wang (2011) present that the convenience yields of emissions allowances are positively related with spot prices, their volatility and previous convenience yields, convenience yields are negatively related with futures prices [13]. Chang et al. (2012) propose a general model of futures options valuation under the term structure of stochastic multi factors, their empirical results show term structure of stochastic multi-factors has a significant effect on futures options valuation for CO_2 emission allowances, and estimate the theoretical futures options valuation by using historical market information [14]. Wang, Huang and Chang (2013) use panel data of weekly corporate bond yields and the fixed effect model with variable intercept [15]. The factors which affect corporate bond spread mainly include bond market complex index, stock market complex index, CPI, bond idiosyncratic volatility and stock idiosyncratic volatility. Li (2008) presents that American options can be exercised at any time during their lifetime, and addresses the optimal stopping time of several kinds of American call options [16]. Shao and Wang (2010) consider the statistical properties of chain reaction of stock indices, the theory of interacting systems and statistical physics are applied to describe and study the fluctuations of two stock indices in a stock market, and the properties of the interacting reaction of the two indices are investigated in the present paper [17]. Athina's (2012) intention of this research is to understand the behavior of the Cyprus Stock Market, his empirical findings of FTSE/CySE 20 show that return distribution takes the shape of a Gaussian distribution at 345 days and the tails appear to become less heavy for less frequent series [18]. The above empirical results examine spot prices, futures prices and their volatility exhibit obviously time-varying trends, thereby spot and futures of emission allowances are all higher risks.

Neri(2011) investigates financial time series model by combining natural computation and agent based simulation, the natural computation technique finds the most suitable parameter for the simulator [19]. Zhou and Mi calculate energy consumption and CO_2 emissions in the year 2010-2030 by taking Chinese industrial structure and energy consumption in each industry into account, and their empirical results show CO_2 emissions can be reduced 1.95 billion tons in 2030 if clear energy account for 20% of total energy consumption [20]. Sekozawa (2012) discusses the options for adaptability to environmental change inherent in Enterprise Resource Planning (ERP) systems, the value of these options, and methods to asses the ERP value [21]. Wu et al. (2012) focuse on combining ultra-capacitor with LiFePO4 battery to improve the performance of energy storage system, the NEDC cycle simulation results demonstrate that compared with the battery only system, the EV with the HESS system is more efficient and the energy efficiency improvement is 3.5% [22]. Hajek (2012) applies several prototype generation classifiers to predict the trend of the NASDAQ Composite index, and demonstrates that prototype generation classifiers outperform support vector machines and neural networks considering the hit ratio of correctly

predicted trend directions [23]. Volos et al. (2012) propose the modelization of coupling between two systems of economic cycles and nonlinear system, their results show that The coupling strength represents the effect of the capital inflow between the two conjugated economic systems, with identical economic aggregates, such as savings, gross domestic product and foreign capital inflow [24]. Neri (2012) discuss a computational simulation technique based on agent based modeling and learning to closely approximate the SP500 and DJIA indexes over many periods and under several experimental set up[25]. Shao and Gao (2004) focus on the contents and models of environmental information disclosure of corporate accounting, and then they proposal a serial of improving environmental information disclosure models suitable to Chinese practice and strengthening environmental protection [26]. Peng and Ren (2004) present environment control as a typical government measure has more important influence, the enterprises proper and right strategic reaction is helpful to have advantage of initial operation and maintains competitive advantage [27]. Yao (2012) propose the implementing of environmental policy determines the effect of environmental regulation with the given environmental control technology and environmental policy, the spring theory model is used to prove existence of the political connection buffer, and the conclusion is that the political connection buffer leads to a bad effect of environmental policy [28]. Zhang and Xu (2012) find, the quantity and quality of environmental performance disclosure of social responsibility report remarkably improved from 2008 to 2010, and have significant differences between geographical regions, between capital markets, and between companies[29]. Yan and Zhong (2012) present that coexistence of economic decentralization and political centralization and excessive competition among local governments guided by central government are core essence of Chinese-style fiscal decentralization [30].

Spot and futures price exhibit time-varying trends in the EU ETS, the convenience yields reflect the difference between spot price and future price of emission allowances. The convenience yields are call or put options, market participants can flexibly adjust portfolio policies of assets exchange between emission allowances spot and futures, and then achieve excess market arbitrage revenues and effectively avoid market risk of emission allowances. Compared with non-ferrous metals, crude oil and natural gas, holding emission allowances need not consume storage cost, are convenience yields significant options features? Convenience yields are implied returns obtained by spot-holders of emission allowances, market participants accurately estimate the convenience yields value and its options value of emission allowances. This paper examine the empirical evidence of exchange options value between spot and futures on the extension of exchange options pricing model, flexibly adjust portfolio size of emission allowance assets, and then achieve excess market arbitrage revenues.

The remainder of our paper is organized as follows. Section 2 analysizes the arbitrage feature of convenience yields. Section 3 describes the sourcing of data samples. Section 4 examines options property of convenience yields. Section 5 estimates and discusses arbitrage revenues of exchanging emission allowances assets using options property of convenience yields. Section 6 provides a brief conclusion.

2 Arbitrage Property of Convenience Yields

Emission allowance is a special credit commodity, holding emission allowance need not storage cost, thereby the convenience yield are the difference between the expected price of spot and futures price of emission allowance based on risk-free interest rate [31-32]. 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, $F_{t,T}$ denotes market price of futures contracts for maturity T at time t, r is the continuously compounded risk-free interest rate. Based on cost-of-carry theory, the theoretical price of emission allowance futures is equal to [31-32]

$$F_{t,T} = e^{(r-cy)(T-t)} S_t \quad (1)$$

Based on the equation (1), the convenience yield is equal to

$$cy = r - \frac{1}{T-t}\ln(\frac{F_{t,T}}{S_t}) \quad (2)$$

Unexpected shocks of market demand and supply induce the market scarcity of emission allowances, spot-holder of emission allowances can achieve excess investment returns with an increase expected price of emission allowances spot in the future, while futures-holders cannot attain excess investment returns. As a result, the convenience yields are excess opportunity cost paid by futures-

holders of emission allowances. GDP growth, government regulatory policies, energy efficiency and promotion and application of low-carbon technology decide long-run total quantity both demand and supply for emission allowance, directly decide their long-run trends. Unexpected interest rate, extreme climate deterioration and energy price volatility induce short-term market shocks of total quantity both market demand and supply. When unexpected market demand assault emission allowances market, market supply will be not significantly increase in the short-term, the market scarcity of emission allowance will increase, and then the raising speed of spot price are greater than the raising speed of futures price, thereby spot-holders can attain excess investment returns.

If expected price of spot is greater than futures price of emission allowances, the convenience yields are positive, market participants can attain extra convenience yields through holding emission allowances spot. The convenience yields will be call options, spot-holders of emission allowances can gain extra options value through purchasing spot substituted for selling futures. If expected price of spot is less than futures price, the convenience yields are negative, and then the convenience yields are put options. Market participants can take contrary portfolio policy to purchase futures substituted for selling spot, futures-holders of emission allowances can gain extra options value. Accordingly market participants flexibly adjust portfolio policy between spot and futures using options property of convenience yields, can effectively avoid market transaction risk induced by price volatility and achieve extra market arbitrage revenues.

3 Data Source

European Union emissions allowances markets have existed two phases: the Pilot phase (2005-2007) and the Kyoto phase (2008-2012). Since European Union implemented banking and borrowing restrictions, spot prices for CO_2 emissions allowances have been decreasing towards zero from October 2006 to December 2007 [33]. In this paper, we choose empirical date samples are from the most liquid and largest CO_2 spot and futures exchange platform in the EU ETS. The spot trading in Bluenext exchange was introduced on June 24, 2005. Now Bluenext exchange has become the most liquid platform for CO_2 spot trading. The futures trading in European Climate Exchange (ECX) which is merged by ICE on August 2010, has started on April 22, 2005. Now ECX (ICE) has become the most liquid and largest platform for CO_2 futures and options trading in the world. 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 CO_2 equivalent. We choose time-serial daily settlement price for EUA futures contracts with different delivery dates going 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 the date samples cover the period from April 8, 2008 to December 20, 2010 in the Kyoto phrase. The free-risk interest rates are 12-month Euribor.

4 Empirical Evidence of Options Property of Convenience Yields

When positive convenience yields are call options, market participants have flexible option to exchange emission allowances assets between spot and futures, and then convenience yields are that market participants gain extra investment returns through holding spot assets substituted futures assets of emission allowances. We assume that market investors freely select financial investment products in the spot and futures market meantime, they can flexibly adjust assets portfolio policies using the convenience yields of emission allowances, and then make correct investment decision. Based on carry-of-cost theory, when $\delta > 0$, that is $e^{r(T-t)}S_t > F_{t,T}$, expected price of spot are greater than futures price of emission allowances at time t, market investor have the option to buy spot assets substituted for selling futures assets, and then they can gain extra investment income through holding emission allowances spot assets. When $\delta < 0$, that is $e^{r(T-t)}S_t < F_t$, futures price are greater than expected price of emission allowances spot at time t, market investors have the option to buy futures assets substituted for selling spot assets, and then they can gain extra investment income through holding emission allowances futures assets. We examine the option property of convenience yields of emission allowances, we propose the following hypothesis.

Hypothesis 1 positive convenience yields of emission allowances are call options, negative convenience yields are put options.

Hypothesis 2 the convenience yields of emission allowances are negatively related with the

spread between futures price and spot price, and they are positively related with the spread between spot price and futures price.

Hypothesis 3 when the convenience yields are positive, convenience yields are positively related with the spread between expected value of spot and futures price of emission allowances, and the absolute value of convenience yields are negatively related with the spread between futures price and expected value of emission allowances spot.

When $cy_t > 0$,

$$cy_t^r = \mathrm{a}_0 + a_1(s_t - f_{t,T}) + \xi \quad (3)$$

$$s_t^{\mathrm{E}} - f_{t,T} = b_0 + b_1 cy_t^p + b_2\xi^{'} + u(cy_t > 0) \quad (4)$$

When $cy_t < 0$

$$\left|cy_t^r\right| = a_0 + a_1(f_{t,T} - s_t) + \xi \quad (5)$$

$$f_{t,T} - s_t^E = b_0 + b_1\left|cy_t^p\right| + b_2\xi^{'} + u(cy_t < 0) \quad (6)$$

Where s_t, f_t denote the logarithm of emission allowances spot and futures, $f_{t,T} - s_t, s_t - f_{t,T}$ denote the spread between futures price and spot price, and the spread between spot price and futures price, cy_t^r, cy_t^p denote the actual convenience yields participated market transaction and the theoretical convenience yields based on constant interest rate, $f_{t,T} - s_t^E, s_t^E - f_{t,T}$ denote the spread between futures price and expected value of spot, and the spread between the expected value of spot and futures price, ξ denote the residual errors in the equation (3) and (5), $\xi^{'}$ denote the options value variable of convenience yields in the equation (4) and (6). When convenience yields of emission allowances are positive, the research data samples cover the period from April 8, 2008 to November 10, 2008, data samples are 155. When convenience yields of emission allowances are negative, the research data samples cover the period from December 5, 2008 to September 30, 2010, data samples are 466.

Table 1 Regression results from hypothesis 1 to hypothesis 3 when $cy_t > 0$

Variable coefficients	F_1	F_2	F_3
b_0	0.0665^{***}	0.0929^{***}	0.1185^{***}
	(509.19)	(701.87)	(525.86)
b_1	2.1924^{***}	3.0285^{***}	3.8955^{***}
	(181.38)	(255.28)	(221.65)
b_2	2.2184^{***}	3.1359^{***}	3.8516^{***}
R^2	(53.59)	(75.98)	(68.84)
	0.996	0.998	0.997
Variable coefficients	F_4	F_5	
b_0	0.1435^{***}	0.1686^{***}	
	(342.87)	(353.37)	
b_1	4.7716^{***}	5.5696^{***}	
	(180.87)	(176.53)	
b_2	4.5486^{***}	5.6326^{***}	
R^2	(54.17)	(65.042)	
	0.996	0.996	

Table 2 Regression results from hypothesis 1 to hypothesis 3 when $cy_t < 0$

Variable coefficients	F_1	F_2	F_3
b_0	0.0007	0.0151^{***}	0.0276^{***}
	(1.094)	(33.30)	(64.29)
b_1	1.6013^{***}	2.4327^{***}	3.2620^{***}
	(28.11)	(64.21)	(126.88)
b_2	1.0161^{***}	1.8091^{***}	2.0614^{***}
R^2	(14.66)	(33.58)	(54.63)
	0.721	0.928	0.980
Variable coefficients	F_4	F_5	
b_0	0.0394^{***}	0.0511^{***}	
	(34.30)	(36.61)	
b_1	4.1167^{***}	4.9965^{***}	
	(87.44)	(96.37)	
b_2	3.0159^{***}	3.8192^{***}	
R^2	(40.27)	(53.50)	
	0.958	0.968	

*Note: 1.***, **, * denote the confidence 99%, 95% and 90% level, the number in the parentheses is t statistic values.*
2. The residual error denote options property of convenience yields for emission allowances

Base on the above hypothesis 1, 2, 3, we propose the empirical evidence from equation (3) to equation (6), the empirical results are shown in the table 1 and 2. Seen from the table 1, when the convenience yields of emission allowances are positive, that is $cy_t > 0$, the related coefficients b_1 between convenience yields and price spread of spot expected value and futures are 2.1924,3.0285,3.8955, 4.7716, 4.5696, the related coefficients b_1 are all positive with an increase of time to maturity of futures contracts for emission allowances, and the related coefficients b_1 exhibit an increasing trend. These signs show that the convenience yields are positively related with the

price spread between spot expected value and futures, and the effect of price spread on convenience yields have an increasing trend with an increase of time-to-maturity of futures contracts. The related coefficients b_2 are 2.2184, 3.1359, 3.8516, 4.5486, 5.6326, they exhibit significant at the 99% confidence level, these signs show that the options property of convenience yields have a significant effect in the equation (4). The related coefficients b_2 exhibit an increasing trend with an increase of time-to-maturity of futures contracts, and options property of convenience yields of emissions allowances have higher significance. Seen from the table 2, when $cy_t < 0$, the related coefficients b_1 are 1.6013, 2.4327, 3.2620, 4.1167, 4.9965, they exhibit an increasing trend with an increase of time-to-maturity of futures contracts, these signs show that the absolute value of convenience yields are positively related with price spread between futures and spot expected value. The related coefficients b_2 are 1.0161, 1.8091, 2.0614, 3.0159, 3.8192, they exhibit a significant effect at the 99% confidence level, these signs show that the options property of convenience yields has a significant effect in the equation (6). The related coefficients b_2 enhance with an increase of time-to-maturity of futures contracts, these signs show the options property of convenience yields exhibit a higher significance. All the regression results from equation (3) to equation (6) exhibit significant at the significance of 99% level, the t-statistical value are significantly greater than 1, these empirical results significantly support hypothesis 1, 2 and 3.

5 Arbitrage Revenues of Assets Exchange of Emission Allowances

Our empirical results show that the convenience yields of emission allowances have a significant options property, market participants can flexibly adjust portfolio policies of assets exchange in the emission allowances spot and futures market meantime using the options property of convenience yields. When the convenience yields are positive, market investors can buy spot assets of emission allowances while selling futures assets. When the convenience yields are negative, market investors can buy futures assets of emission allowances while selling spot asset. The above portfolio policies of assets exchange can create significant options value of assets exchange.

Assumed that market investors are risk-neutral, strike cost of assets exchange between spot and futures of emission allowances are equal to zero, spot price s_t and futures price f_t follow Brownian motion.

$$\begin{aligned} ds_t &= \mu_s s_t dt + \sigma_s s_t dz_s \\ df_t &= \mu_f f_t dt + \sigma_f f_t dz_f \end{aligned} \tag{7}$$

Where s_t, f_t denote the logarithm of spot price and futures price of emission allowances, μ_s, μ_f denote the instantaneous returns of spot price and futures price, σ_s, σ_f denote the market volatility of spot price and futures price, which don't vary in the period of assets holding, dz_s, dz_f denote the increment of a standard Wiener process, and $dz_s dz_f = \rho dt$, where ρ denote the related coefficient between spot price and futures price, and the related coefficient ρ is constant in the period of assets exchange. Assumed risk-free interest rate is r , emission allowances are credit assets, storage emission allowances need not cost, $f_t^c = F(t,T)e^{-r(T-t)/365}$ denote discounted futures price of emission allowances on the basis of risk-free interest rate. We propose the extension of Margrabe's options pricing model of assets exchange in order to estimate the options value of convenience yields of emission allowances. When $cy_t > 0$,spot-holders of emission allowances can gain extra convenience yields, market investors have a option to buy spot assets while selling futures assets, the options value of assets exchange between spot and futures is equal to [4-5][34]

$$\begin{aligned} &V(s_t, f_t, \tau) = S_t(0)\phi(d_1) - f_t^c(0)\phi(d_2) \\ &d_1 = \frac{\ln\frac{E(s_t)}{E(f_t^c)} + \frac{\sigma^2\tau}{2}}{\sigma\sqrt{\tau}}, d_2 = \frac{\ln\frac{E(s_t)}{E(f_t^c)} - \frac{\sigma^2\tau}{2}}{\sigma\sqrt{\tau}} = d_1 - \sigma\sqrt{\tau} \\ &\sigma^2 = \sigma_s^2 + \sigma_f^2 - 2\rho\sigma_s\sigma_f \end{aligned} \tag{8}$$

Where $\mathrm{E}(s_t), E(f_t)$ denote the average value of spot price and discounted futures price in the period of assets exchange, $s_t(0), f_t(0)$ denote spot price and discounted futures price at the initial period of assets exchange, τ denote the assets-holding period, $\phi(.)$ is normal distribution. When $\delta < 0$, expected value of spot are less than futures price of emission allowances, the convenience yields are put options, market investors have a option to buy futures assets while selling spot assets, and then they can achieve extra market arbitrage revenues.

Table 3 The correlation between emission allowances spot and futures

ρ	ρ_{sf_1}	ρ_{sf_2}	ρ_{sf_3}
$\tau_1\ (cy_t > 0)$	0.9840	0.9722	0.9596
$\tau_2\ (cy_t < 0)$	0.9736	0.9537	0.9202
ρ	ρ_{sf_4}	ρ_{sf_5}	
$\tau_1\ (cy_t > 0)$	0.9369	0.9362	
$\tau_2\ (cy_t < 0)$	0.8826	0.8586	

Note: ρ_{sf} denote the correlation coefficient between emission allowances spot and futures, τ_1, τ_2 denote the asset-holding period of positive convenience yields and negative convenience yields.

In the table 3, when the convenience yields are positive, the correlation coefficients between emission allowances spot and futures are 0.9863, 0.9762, 0.9657, 0.9448 and 0.9432 in the asset-holding period τ_1,the related coefficients ρ reduce with an increase of time-to-maturity of futures contracts. When the convenience yields are negative, the related coefficients ρ decrease with an increase of time-to-maturity of futures contracts in the asset-holding period τ_2.

Table 4 Market arbitrage revenues of assets exchange and statistical description of each variable when $cy_t > 0$

variable	F_1	F_2	F_3
cy_t	$cy_t > 0$	$cy_t > 0$	$cy_t > 0$
τ_1	0.592	0.592	0.592
F *EX* S	F_1 *ex* S	F_2 *ex* S	F_3 *ex* S
σ	0.5073	0.6712	0.8112
d_1	0.3249	0.3893	0.4345
d_2	-0.0653	-0.1270	-0.1896
$V(s_t, f_t, \tau)$	4.5377	5.8330	6.8472
S *EX* F	S *ex* F_1	S *ex* F_2	S *ex* F_3
d_1	0.0653	0.1270	0.1896
d_2	-0.3249	-0.3893	-0.4345
$V(f_t, s_t, \tau)$	2.6513	3.5293	4.3258
Arbitrage revenues	1.8864	2.3037	2.5214
variable	F_4	F_5	
cy_t	$cy_t > 0$	$cy_t > 0$	
τ_1	0.592	0.592	
F *EX* S	F_4 *ex* S	F_5 *ex* S	
σ	1.0597	1.1364	
d_1	0.5002	0.5414	
d_2	-0.3150	-0.3328	
$V(s_t, f_t, \tau)$	8.4035	8.9842	
S *EX* F	S *ex* F_4	S *ex* F_5	
d_1	0.3150	0.3328	
d_2	-0.5002	-0.5414	
$V(f_t, s_t, \tau)$	5.9629	6.2826	
Arbitrage revenues	2.4406	2.7016	

Table 5 Market arbitrage revenues of assets exchange and statistical description of each variable when $cy_t < 0$

variable	F_1	F_2	F_3
cy_t	$cy_t < 0$	$cy_t < 0$	$cy_t < 0$
τ_1	1.8192	1.8192	1.8192
S *EX* F	S *ex* F_1	S *ex* F_2	S *ex* F_3
σ	0.3698	0.4877	0.6460
d_1	0.2792	0.3851	0.5202
d_2	-0.2195	-0.2726	-0.3512
$V(f_t, s_t, \tau)$	2.8195	3.6921	4.9168
F *EX* S	F_1 *ex* S	F_2 *ex* S	F_3 *ex* S
d_1	0.2195	0.2726	0.3512
d_2	-0.2792	-0.3851	-0.5202
$V(s_t, f_t, \tau)$	2.6180	3.4362	4.4637
Arbitrage revenues	0.2015	0.2559	0.4531
variable	F_4	F_5	
cy_t	$cy_t < 0$	$cy_t < 0$	
τ_1	1.8192	1.8192	
S *EX* F	S *ex* F_4	S *ex* F_5	
σ	0.7900	0.8741	
d_1	0.6594	0.7430	
d_2	-0.4061	-0.4359	
$V(f_t, s_t, \tau)$	6.8325	7.5822	
F *EX* S	F_4 *ex* S	F_5 *ex* S	
d_1	0.4061	0.4359	
d_2	-0.6594	-0.7430	
$V(s_t, f_t, \tau)$	5.0697	5.5638	
Arbitrage revenues	1.7628	2.0183	

Note: ex denote assets exchange, S EX F denote spot assets exchange futures assets, F EX S denote futures assets exchange spot assets.

In the table 4, take an example for spot assets S exchanging futures assets F_1, when $cy_t > 0$, market participants have a option to hold spot assets S while selling futures assets F_1, the convenience yields are call options, and then they can attain 4.5377€ per ton options value of assets exchange through spot assets S exchanging futures assets F_1. If we don't consider the options property of

convenience yields, market participants select portfolio policy of holding futures assets F_1 while selling spot assets S, they can gain 2.6513€ per ton options value of assets exchange through holding futures assets. When the convenience yields are positive, market participants can achieve extra 1.8864€ per ton market arbitrage revenues through futures assets F_1 exchanging spot assets S. When the convenience yields are positive, based on similar portfolio policies of assets exchange market participants can gain extra 2.3037€, 2.5214€, 2.4406€ and 2.7016€ per ton market arbitrage revenues through futures assets F_2, F_3, F_4, F_5 substituted for spot assets S. In the table 5, when the convenience yields are negative, market participants have a option to hold futures assets F_1 while selling spot assets S, and then they can gain 2.8195€ options value of assets exchange through holding futures assets F_1. If we don't consider the options property of convenience yields, market participants select the portfolio policy of holding spot assets S while selling futures assets F_1 ,and then they can gain 2.6513€ per ton options value of assets exchange through assets exchange policy. As a result, when the convenience yields are negative, market participants can achieve extra 0.2015€ per ton market arbitrage income through holding futures assets F_1 substituted for spot assets S .when the convenience yields of emission allowances are negative, based on similar portfolio policies of assets exchange, market participant can achieve extra 0.2559€, 0.4531€, 1.7628€ and 2.0183€ per ton market arbitrage income through holding futures assets F_2, F_3, F_4, F_5 substituted for spot assets S. In brief, market participants can flexibly adjust portfolio policies of assets exchange between emission allowances spot and futures assets using the options property of convenience yields, and then they can attain extra market arbitrage revenues. Market participant can gain increasing arbitrage revenues with an increase of time-to-maturity of futures contracts. The above empirical results fully support hypothesis 1, 2 and 3 about the options property of convenience yields.

6 Conclusion

Based on data samples using EUA spot and futures in the ICE and BLUENEXT exchange platform in the European Union emissions trading scheme (EU ETS), we propose the empirical evidence the options property of convenience yields and market arbitrage revenues through assets exchange between spot and futures on the extension of Margrabe's options pricing model of assets exchange. We present the following innovative results. When the convenience yields of emission allowance are positive, the convenience yields are positively related with the spread between spot expected value and futures price. When the convenience yields of emission allowances are negative, the absolute value of convenience yields are negative related with the spread between futures price and expected value of spot, and convenience yields of emission allowances have a significant options property. The related coefficients between spot price and futures price exhibit an inclining trend with an increase of time-to-maturity of futures contracts. When the convenience yields are positive, the convenience yields are call options, market participants can flexibly adjust portfolio policy of assets exchange to buy spot assets while selling futures assets, and then they can achieve extra market arbitrage revenues using the options property of convenience yields. When the convenience yields are negative, convenience yields are put options, market participants have a option to buy futures assets while selling spot assets, and then they can attain extra market arbitrage revenues through assets exchange. Market participants can achieve increasing market arbitrage income with an increase of time-to-maturity of futures contracts.

Chang and Wang (2011) present the significant relationship between convenience yields and options value of futures spreads in the emissions allowances markets [35]. Futures prices spreads contain expected futures prices as risk-free interest rate and convenience yields value, futures spreads options estimated by Chang and Wang (2011) contain options values of the above two parts. In the actual emissions allowances markets, convenience yields exhibit time-varying trends. We confirm that the options property of convenience yields from the theoretical and empirical analysis. Based on extension of exchange options pricing model, we compare different assets portfolio policies through exchanging assets between spot and futures, our empirical results verify that market participants can make more scientific assets portfolio policies using the options property of convenience yields, and then achieve extra market arbitrage revenues through

exchange assets. Unexpected market information exerts the unexpected market scarcity, it pushes up the higher prices volatility both spot and futures, the investors, hedgers, arbitragers should be aware of risk reduction between spot and futures assets. Kai et al (2012) find that price series both spot and futures with different maturities for emission allowances have significant ARCH effect using GARCH model, have strong volatility clustering effect, and then continuous property in price exhibit significant evidence, spot and futures price have obvious leverage effect, and then the asymmetric effect in price volatility can promote price volatility both spot and futures [36]. The overreaction of emissions allowances markets bring markets participant about many arbitrage opportunities, so short-term market speculations are active. The higher volatility and significantly clustering effect of convenience yield brings market hedgers about the greater arbitrage returns through adjusting assets portfolio policies. Market participants can flexibly adjust their assets portfolio policies and then achieve extra market arbitrage returns using the options property of convenience yields. An active hedging strategy involving different spot and futures markets seems to be interest in the options property of convenience yields and achieving excess market arbitrage revenues through exchanging assets in order to gain higher risk reduction of assets portfolio.

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