Universidade de Aveiro
Departamento de Economia, Gestão e Engenharia Industrial

Documentos de Trabalho em Economia
Working Papers in Economics

Área Científica de Economia
E/nº 54/2010

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Submission of Papers for Publication (Para submissão de artigos para publicação): Prof. Sílvia Jorge (sjorge@ua.pt).

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Abstract

In this work we analyze, explore and measure two of the most important concepts for the theory of storable commodity markets. After analyzing the statistical properties of spot and futures EU ETS allowances for Germany and France, we model and test the risk premium and convenience yield for CO_2 contracts accordingly to previous economic theories, for the period 2005-2009. Results indicate that convenience yields are positively related to the spot CO_2 return while being negatively influenced by the spot volatility. This negative impact of spot volatility is also verified for the risk premium, with the latter varying positively with time to maturity. Contradicting previous empirical findings, we found only a positive influence of the convenience yield on the risk premium for the ECX French market and for Phase II contracts, leading us to conclude that results are Phase, market and data span dependent. Moreover, results are independent on the volatility forecast used and important for risk management purposes for allowances markets participants. Moreover, day-ahead markets for CO_2 are in "*normal contango*" for the entire data period under analysis, contrary to previous empirical findings for the allowances market.

Keywords: CO_2 Emission Allowances; Volatility; Volume; Maturity; Convenience Yield; Risk Premium; Spot Prices; Futures Prices

JEL classification: C22; C32;G12; G14; Q51

*This paper was prepared for and presented at the Energy & Finance Conference, October 6 to 8, 2010, which took place in Essen, Germany. We thank the useful comments.

1 Introduction

Global warming is a growing concern in our days, and the European Union (EU) clearly indicated its will to take the lead in the fight against it when in 2005 they decided to trade European Union allowances (EUAs), each representing the right to emit one ton of CO_2 in the atmosphere.

Established under Directive 2003/87/EC, the EU ETS (EU Emissions Trading Scheme) regulates the carbon dioxide emissions (CO_2) from installations across the EU and includes power generation, mineral oil refineries, offshore installations, and other heavy industrial sectors in its first phase from 2005-2007 ("Phase I") and in its second phase from 2008-2012 ("Phase II") to coincide with the first Kyoto Commitment Period. Further 5-years phases will follow and CO_2 emission allowances are currently being traded on electricity power exchanges (Powernext in France, who trades CO_2 spots, and European Climate Exchange (ECX), who trades futures based on these spots), and European Energy Exchange (EEX) in Germany, who trades both spot and futures contracts on CO_2 allowances, being these the countries we will analyze simultaneously).

With these growing concerns, CO_2 has become a kind of tradable good. Initially each member state decides through the National Allocation Plan how much EUAs to emit and how those will be distributed to each installation. If an installation emits below its level then at the end of the compliance year it can trade the excess EUAs; or it may need to buy EUAs due to excess emission in a given year, otherwise it will be forced to pay an excess emissions penalty. With the evolution of the carbon trading market, not only the carbon spot market but also some derivative markets such as the carbon futures market and option market have gradually emerged.

Previous author's analyzed CO_2 spot price behavior (Benz and Trück, 2009; Paolella and Taschini, 2008; Seifert, Uhrig-Homburg and Wagner, 2008; Daskalakis, Psychoyios and Markellos, 2009) and CO_2 futures markets (Uhrig-Homburg and Wagner, 2006, 2007; Wei et al., 2008), but there is still a lack of understanding about the behavior of risk premiums and convenience yields for the allowances EU ETS market.

Wei et al. (2008) discuss the liquidity of the EU ETS futures market. Paolella and Taschini (2008) provide an econometric analysis addressing the unconditional tail behavior and the heteroskedastic dynamics in the returns on CO_2 and SO_2 (US markets) allowances. While Uhrig-Homburg and Wagner (2006) investigate the success changes and optimal design of derivatives on emission allowances, Seifert, Uhrig-Homburg and Wagner (2008) develop a stochastic equilibrium model reflecting in a stylized way the most important features of the EU ETS and analyze the resulting CO_2 spot price dynamics. Daskalakis, Psychoyios and Markellos (2009) find some evidence that market participants adopt standard no-arbitrage pricing using spot and futures prices from the EEX EU ETS in Germany. Benz and Trück (2009) evaluate price, volatility and density forecasts allowing for heteroskedasticity using ARCH, GARCH or regime-switching models in CO_2 markets.

There are also some previous works related to risk premium but applied for electricity and other energy markets. Pindyck (2001) has investigated the futures market for crude and heating oil, finding evidence of backwardation in the markets, where it is larger during times of high volatility. Logstaff and Wang (2004) finds evidence of positive risk premiums in futures for the PJM electricity market and negative implied excess yields. Botterud, Battacharyya and Ilic (2002) found similar results for the Nordic electricity market. Fama and French (1988) found that violations in the Samuelson effect may occur when inventory is high, where forward price volatilities can initially increase with contract maturity. Redl et al. (2009) also find a positive forward premia in electricity prices for EEX and Nord Pool from 2003 to 2008. Wei and Zhu (2006) analyze convenience yields and risk premium for the natural gas market.

Back to the CO_2 market, Chevallier, Ielpo and Mercier (2009) provide statistical evidence that the cost-of-carry relationship does not hold between the 2008 and 2009 contracts for CO_2 allowances spot and futures prices, but Uhrig-Homburg and Wagner (2007) use cointegration methodology to reveal evidence that spot and futures prices are linked by the cost-of-carry approach, also finding that futures markets lead the price discovery process of CO_2 emission certificates using the vector error correction model (VECM). A more direct related study to ours is Chevallier (2010) who investigates the measure of risk-premia in CO_2 allowances spot and futures prices from Bluenext (France) and ECX, respectively. They found positive time-varying risk premia in CO_2 spot and futures prices, higher for post-2012 contracts than for Phase II contracts, contradicting the findings of Benth, Cartea and Kiesel (2008) for electricity markets. Also, contrary to Bessembinder and Lemmon (2002) for the electricity market, Chevallier finds a positive relationship between risk premia and the variance of CO_2 spot prices.

Literature applied to the study of convenience yields in CO_2 allowances is even sparser. However, for the German market, Borak et al. (2006) investigate the nature of convenience yields for CO_2 emission allowance futures. They found that the market has changed from initial backwardation to Contango with significant convenience yields, where a high fraction of the yields can be explained by the price level and volatility of the spot prices. They have used all spot and futures quotes available from October 2005 to September 2006, which comprises only the first year of futures trading at EEX.

In this paper we examine two of the most important concepts in finance, the risk premium and convenience yield, for the French Bluenext and German EEX markets simultaneously, to get further lights about the behavior of spot and futures CO_2 markets. The contribution of this paper is fourfold: First, it helps to identify the internal dynamics of widely traded CO_2 emission allowances, which is essential in pricing of the contracts. Secondly, we aim to fill the gap in the literature about the carbon market by examining both concepts, for two newly established derivatives market. Thirdly, we compare the results obtained for two European markets, extending the period of analysis to both Phase I and Phase II periods, while most of the previous empirical works analyzing spot and futures carbon allowances were based on Phase I data or data covering only a small period of Phase II data. Fourth, the implications of the study are expected to be functional for risk managers and individual investors dealing with the carbon allowances trading markets. We also aim to shed light on the way the sign of forward premiums informs about the behavior of market agents, which is always of concern to regulators when designing the rules for a competitive market. It is expected that the implications of the study will be useful for hedgers and speculators dealing with European CO_2 allowances futures.

The rest of the work evolves as follows. Section two presents the data to be used in the empirical part while accounting for market differences and exposing the data statistical properties. In the third section, empirical methodologies are presented, while results are showed and discussed in section 4. Section 5 concludes.

2 Data

The data analyzed in this paper covers the period from 2 July 2005 for the ECX market, and from October 4, 2005 for EEX, while for both until October 8, 2009, covering both the First (2005-2007) and Second (2008-2012) period of European Carbon Futures. Data used comes from the EEX and ECX official websites[1] and corresponds to daily data. For the spot CO_2 price we have divided the sample period into two sub periods to separate the analysis into a Phase I period (04/10/2005 - 29/11/2007 for EEX and 02/07/2006 - 29/11/2007 for ECX) and a Phase II period (25/03/2008 – 08/10/2009 for both markets).

The EEX is located in Leipzig, established in 2002, providing the framework for trading of both electricity contracts and EUAs, being considered one of the largest power markets in Europe.

EUAs spot trading regarding greenhouse gases began in the early 2005, while since August of the same year it started providing clearing services for the OTC trading of EUAs. These EU emission allowances grant the owner of a plant in an EU member state the right to emit one metric ton of CO_2. Spot contracts regarding EU emission allowances have a contract volume of 1 EUA and are traded in EUR per EUA. The settlement price is established after the end of trading on every exchange trading day.

In 2005, futures on physical electricity and European Carbon Futures (ECFs) started to be trading in EEX. Depending on when the actual delivery of the EUAs takes place, ECFs are characterized as First and Second period. In the first period ECFs maturing on December 2006 and 2007 are traded. With regard to the Second Period European Carbon Futures, futures contracts reaching maturity in December 2008, December 2009, December 2010, December 2011 and December 2012 can be traded. We will analyze risk premia and convenience yields

[1] We would like to thank the EEX market for providing us with the necessary data.

for each future contract separately. For each contract the penultimate exchange trading day in November corresponds to the last day of trading.

As for the other market, the European Climate Exchange (ECX) EUA Futures contract were the first emissions products to be listed on the Intercontinental Exchange (ICE) Futures Europe platform in UK on April 22, 2005. ECX EUA Futures are based on underlying EU allowances (EUAs) and provide the market with standardized contract terms and a benchmark for price discovery. ICE/ECX continues to be the most liquid and transparent platform for EUA trading offering transparent screen trading with tight spreads as well as the clearing of over-the-counter positions. Contracts are listed on an quarterly expiry cycle such that March, June, September and December contract months are listed up to March 2013 and annual contracts with December expiries for 2013 and 2014.

Trading of emission allowance futures contracts is primarily performed through the European Climate Exchange (ECX). Since the ECX does not allow spot EUA trading, it uses Powernext spot prices as a reference for the futures contracts. The futures are physically settled three days after expiry with the maturity date being the last business day of December in ECX. Bluenext is the market place dedicated to CO_2 allowances based in Paris, created on June 24, 2005, and integrated in the French Powernext market.

As argued by Daskalakis, Psychoyios and Markellos (2009), the pricing mechanism and relationship between spot and futures allowance prices may vary considerably depending on if the futures contract is written and expires in the same phase or between different phases of the EU ETS, respectively. Given these idiosyncrasies of the markets, the present study analyses spot market data along with futures market data from contracts with both inter-phase and intra-phase expirations.

Figure 1 (see appendix), depicts the evolution of the spot price and EUA futures contracts for all delivery dates considered (from 2006 to 2012) for ECX and EEX. Summary statistics of the data for both markets is provided in table 1 (see appendix).

From October 2006 until December 2007, CO_2 spot prices have been decreasing towards zero in the EEX due to the banking[2] restrictions implemented between 2007 and 2008 (Alberola

[2]Banking of allowances means the carrying forward of the unused emission allowances from the current year

and Chevallier, 2009). Moreover, as showed by the mentioned authors banking restrictions between 2007 and 2008 caused the disconnection of spot and futures prices between Phase I and Phase II. Besides this also a structural break for carbon prices of all maturities occurred in April 2006 due to information revelation (Alberola, Chevallier and Chèze, 2008). The 2008 onwards decreasing EUAs prices are justified by the decreasing volume demand, a product of the worldwide financial crisis. EUAs were traded at €15 in March 2007, then stayed in the range of €19-25 until July 2008, and decreased steadily afterwards to achieve €8 in February 2009. Notice that the series behavior for both markets is very similar and we are able to see the same up and down movements for futures series in both, except for the spot which has been relatively stable in the Bluenext market but decreasing for the EEX for the 3 first quarters of 2007.

By a first visual inspection of future plots we may observe that futures prices for delivery during Phase II proved to be much more reliable than futures prices for delivery during Phase I due to the banking restrictions enforced between the two Phases (Alberola and Chevallier, 2009). Contrary to previous literature that has been concentrated mostly on Phase I futures contracts, we also have data corresponding to Phase II alowances contracts. For the ECX market we also have data for the Phase I contract FutDec05 and for two of the contracts maturing on Phase III (2013-2020), which are FutDec13 and FutDec14.

Descriptive statistics for returns of EEX and ECX futures contracts are presented in table 1 (see table 1 in the appendix). We may observe that futures of all maturities present negative skewness and excess kurtosis (for a normal distributed random variable, skewness is zero and kurtosis is three).

We are working here with the log first difference of spot and futures prices, computed as $f_t = \log F_t - \log F_{t-1}$ and $s_t = \log S_t - \log S_{t-1}$, where the low case letters are meant to be returns and F and S stand for future and spot price levels, respectively. Given that we work with logarithmic returns, price stationarity would not be a problem, as the variables are stationary

for use in the following year. The banking of allowances is now permitted within Phases (except for France and Poland), but it was prohibited from 2007 to 2008 (inter-phase). This had significant implications for the pricing of emission allowance and its underlying derivatives, where we have seen prices decreasing towards zero between both phases (Daskalakis and Markellos, 2008). Nevertheless, industries are allowed to bank the unused permit from Phase II to Phase III in France and Germany.

at their log first difference[3]. We may observe from this table the absence of normality in the returns, and data fat tail leptokurtic distributions are also evident. Also, emission allowances are characterized by high historical volatility, as they were also previously in the literature[4].

We may also observe that for both EEX and ECX markets, volatility is higher for FutDec06 and FutDec07, which should be expected given the immaturity of the market in Phase I. Future 2008 contracts through Futures 2012 contracts evidence a much more similar volatile behavior between them and we can infer from here that the market start learning at the beginning of Phase II and remain learning onwards. Therefore, allowances seem to have started to produce the environmental desired effects from this date forward.

3 Methodology

A necessary condition for prediction of future spot prices from future contract prices is the presence of market efficiency. Market inefficiency may exist for two reasons: 1) expectations are not rational; 2) the existence of a non-zero risk premium. Under rational expectations, if the future price is not an unbiased estimator of future spot price, the existence of a risk premium is implied. On the other hand, the risk premium is influenced by the degree of risk aversion and the covariance of asset returns (or prices).

Basic financial literature argues that forward discounted prices should equal current spot prices. However, for every moment t in time, the futures price $F_{t,T}$ of CO_2 allowances with delivery in T can be greater than the current spot price S_t (the expected spot price at delivery T, $E_t(S_T)$). In this case the market is said to be in *contango* (normal *contango*). When the futures price $F_{t,T}$ is less or equal than the current spot price S_t (expected spot price in T, $E_t(S_T)$), the futures market is said to exhibit *backwardation* (normal *backwardation*). Normal *backwardation* is equivalent to a positive risk premium (or negative forward premium, Keynes, 1930) since the risk is transferred to the long position[5] in futures.

[3] Results will be provided upon request.

[4] See Paolella and Taschini (2008) and/or Daskalakis, Psychoyios and Markellos (2009) for a detailed description of the statistical properties of the EUA price series.

[5] The buyer of the future contract is said to have a long position, while the seller a short position.

According to the theory of storage in addition to interest foregone through the commodity, storage costs for holding the commodity and a convenience yield on inventory has to be considered. This approach is resumed in the relation:

$$F_{t,T} = S_t e^{(r+sc-\psi)(T-t)} \tag{1}$$

where $F_{t,T}$ is the futures price at time t for delivery in T, S_t is the spot price at time t, r is a constant interest rate[6], sc are storage costs, and ψ stands for the convenience yield which represents the benefit obtained by the physical detention of the asset, in using or applying it. In other words, the convenience yield is the incremental value of spot prices over futures prices after accounting for carrying costs. According to this theory, if the futures price deviates from this relationship, then arbitrageurs would be able to make risk-free profits. However, in CO_2 markets storage costs are null[7].

We follow Pindyck (2001) assuming that differences between the current spot price and futures prices can be explained by interest in storing and a convenience yield. If we assume no arbitrage possibilities between spot and futures markets we can derive a formula for the convenience yield. Let´s assume we hold a unit of emissions rights at time t, being the current spot price S_t. Assuming the existence of a convenience yield, holding the emission right until maturity will pay the return (Borak et al., 2006):

$$S_T - S_t + \psi_{(T-t)} \tag{2}$$

where $\psi_{(T-t)}$ is the convenience yield associated with holding the allowance from t to T. If at the same time we short a futures contract for delivery in T, its return will equal $F_{t,T} - S_T$.

[6] We have assumed a constant interest rate in the estimations performed of 4%. Sensitivity analysis performed on this interest revealed that the main conclusions remain unchanged.

[7] They only exist on company's balance sheets.

Given the no-arbitrage argument we should have:

$$S_T - S_t + \psi_{(T-t)} + F_{t,T} - S_T = \left(e^{r(T-t)} - 1\right) S_t \quad (3)$$
$$\Leftrightarrow \psi_{(T-t)} = S_t e^{r(T-t)} - F_{t,T}$$

which represents the equation for the convenience yield. Since the positions are covered, there is no risk involved in the transaction and the total return turns out to be non-stochastic (Wei and Zhu, 2006). The returns should be the same as the return of a risk-free investment, whose return is r, with price S_t.

In CO_2 allowances, expectations and risk preferences of market participants will determine futures prices. According to this approach the futures price is split into the expected future spot price and a risk premium. As such, if risk premia exist, futures prices are not unbiased predictors of future spot prices. An assumption of unbiased futures prices would result in incorrect estimates of future spot prices and inefficient decisions of market participants in CO_2 markets.

There are several ways that business can protect themselves from the risk that comes from the uncertainty of future prices. CO_2 futures, for instance, are ways for companies to hedge against these fluctuations and potential risk by allowing buyers to contractually purchase allowances at a designated price at some point in the future. Risk premiums are priced into these contracts and reflect how much risk is associated with buying that contract. The more risky a futures contract is, the higher the risk premium is for that contract, and the higher the potential profit.

The risk premium can be thought of as a compensation to market participants for bearing risk, that is, for holding a risky investment instead of a risk-free one. As argued by Bessembinder and Lemmon (2002) and Longstaff and Wang (2004), electricity risk premia represent a compensation for the volatility of unexpected changes in prices and demand. As allowance demand fluctuates in response to other energy markets and weather conditions, we expect risk premia to vary in magnitude over time. Samuelson (1965) founds a typically declining term structure in the volatility of futures prices as maturity increases (the term structure of a commodities forward price volatility), which became known as the Samuelson effect or time-to-maturity effect.

Formally, let $E_t(S_T)$ be the expectation today (time t) for the CO_2 spot price at time T, and $F_{t,T}$ the price today of a future contract written on CO_2 EU ETS that matures at time T. The risk premium (π) in monetary units is then given by:

$$\pi_t = F_{t,T} - E_t(S_T) \tag{4}$$

As argued by Weron (2008) many authors use the forward premium (FP) as being the risk premium (π), although $\pi =$ -FP. Chevallier (2010) also uses the forward risk premium, referring to it as the risk premium. We follow the latter and use here the forward risk premium, while referring to it as the risk premium.

We compute the risk premium of CO_2 allowances at time t as the difference between the traded futures price and the ex-post delivery spot price (Chevallier, 2010), where the spot price at time T (the ex-post delivery futures price $F_{T,T}$) is used as a proxy of the expected futures price at time t with delivery in T, $E_t(F_{T,T})$:

$$\pi_t = F_{t,T} - S_T \tag{5}$$

Furthermore, we compute this risk premium in CO_2 allowance prices for all contracts with delivery between 2006 and 2012 in EEX and with delivery between 2005 and 2014 for the ECX market. Given that allowance demand varies through time depending on weather and other energy markets we expect this risk premium to vary also in magnitude over time.

The adequacy of the risk premia approach for CO_2 futures prices suggest that the futures prices cannot be seen as unbiased estimators of the expected future spot price. Rather they reflect the demand and supply for hedging instruments (Karakatsani and Bunn, 2005).

Previous studies on electricity market forward risk premium feature that risk premia in electricity markets are a negative function of time-to-maturity (Benth, Cartea and Kiesel, 2008; Diko, Lawford and Limpens, 2006). In order to test this relationship between time-to-maturity and forward risk premium, but this time for the allowances market, we estimate the following model:

$$\pi_t = \alpha + \beta\tau_t + \delta\tau_t^2 + \varepsilon_t \tag{6}$$

where α is the constant term, $\tau_t = T - t$ represents the remaining time-to-maturity of the underlying contract, and ε_t is an i.i.d. Gaussian white noise error with mean 0 and variance σ^2. Time-to-maturity is computed as the difference in calendar days between the trading day t and the first day of the delivery period for the underlying contract. The constant term α represents the overall level of relative hedging pressure, whereas β and δ coefficients determine the relationship between risk premia and time-to-maturity.

We will thus examine the empirical determination of the convenience yield and risk premium separately.

We have already seen that the convenience yield is the benefit of holding the storage commodity. It depends on several factors (Pindyck, 2001) as the current price level, the price volatility and level of storage (for the explanations see Wei and Zhu, 2006). In CO_2 allowances there is no physical storage cost for holding an emission right as previously mentioned (Borak et al., 2006).

Our empirical convenience yield can then be specified as follows:

$$\psi_t = \beta_0 + \beta_1 s_t + \beta_2\sigma_t^2 + \varepsilon_t \tag{7}$$

where ψ_t is the marginal convenience yield as defined in (3), s_t is the log spot difference price of emission allowances, σ_t^2 is the price volatility modeled as a GARCH(1,1)[8]. If the theories are correct, we should expect both β_1 and β_2 to be positive. The positive relation (correlation) between spot price and the convenience yield is consistent with the theory of storage: when inventories decrease (or increase) the spot price will increase (or decrease) and the convenience yield will also increase (or decrease), because futures prices will not increase (or decrease) as

[8]We will specify the volatility forecasting measures below, but for the convenience yield regression we have just used the GARCH(1,1) specification given that results obtained were very similar using other common volatility forecasting measures.

much as the spot price.

To verify the theory of commodity prices we also regress the extracted risk premium component on the convenience yield and price volatility. The risk premium is then modeled as:

$$\pi_t = \beta_0 + \beta_1 \sigma^2_{s,t} + \beta_2 \psi_t + \varepsilon_t \tag{8}$$

We perform the risk premium regression in this way since Considine and Larson (2001) suggest the risk premium to be positively related to price volatility, and Schwartz (1997) suggest that the risk premium should be positively related to the convenience yield.

Given that different approaches could be used to measure the volatility of the spot price in period t, and in order to see if results change to different specifications, we consider four commonly-used volatility proxies to study volatility impacts on risk premiums: the daily squared returns, the rolling window approach, the risk metrics estimator and the GARCH(1,1) model. We then consider the four simple volatility forecasting models that are widely used in industry (Anderson et al., 2006; Poon and Granger, 2003). In what follows we also consider the problem of forecasting the conditional variance of the daily returns of CO_2 allowance prices. Therefore, the time varying conditional variance is obtained for equation (8) in four different ways, but given the similar results we will only present these estimates for the EEX market.

Being s_t the log spot price difference of emission allowances, a commonly used volatility proxy is the squared return, s_t^2. Assuming a normal conditional distribution of daily returns:

$$s_t | \mathcal{F}_{t-1} \sim N(0, \sigma^2_{s,t}) \tag{9}$$

where $N(0, \sigma^2_{s,t})$ is a Normal distribution with mean zero and variance $\sigma^2_{s,t}$, and $\mathcal{F}_{t-1}$ is the information set used in defining the conditional variance of interest. But then $E_{t-1}\left[s_t^2\right] = \sigma^2_{s,t}$ and the squared daily return is a valid volatility proxy.

First we perform the risk premium estimates of equation (8) based on the daily return measure of volatility:

$$h_{1t} = \sigma^2_{s,t} = s_t^2 \tag{10}$$

where s are spot CO_2 price returns, measured as the log first differences of CO_2 spot prices, being h_{1t} the forecast of the conditional variance of s_t using daily squared returns.

Second, we consider the volatility forecasting model based on a 60-day rolling window forecast given by:

$$h_{2t} = \frac{1}{60} \sum_{j=1}^{60} s_{t-j}^2 \tag{11}$$

where $h_{2t}$is the forecast of the conditional variance of s_t when the forecast measure is based on rolling regressions. Rolling sample windows arguably provide the simplest way of incorporating actual data into the estimation of time-varying volatilities, or variance. The number of days ($p = 60$) considered in the method determines the variance-bias trade-off of the estimator, with larger values of p reducing the variance but increasing the bias (Anderson et al., 2006). For instance, in the empirical finance literature, it is quite common to rely on rolling samples of 60 days (Patton, 2008) or on rolling samples of five-years of monthly data, corresponding exactly to $p = 60$ (Anderson et al., 2006), in estimating time-varying variances.

Third, RiskMetrics (J. P. Morgan, 1996) are also used, where they construct daily volatility measures for a wide range of different financial rates of return:

$$h_{3t} = \lambda h_{3t-1} + (1 - \lambda)\, s_{t-1}^2; \lambda = 0.95 \tag{12}$$

We also used the GARCH(1,1), or else σ_t^2 will be the price volatility modeled as a GARCH(1,1). We assume a simple variance structure using the GARCH(1,1) model for the spot, for the tractability of the estimation, which simultaneously captures the time-varying aspect. This was the only volatility proxy used for estimation of equation (7), given that results revealed to be very similar. The GARCH(1,1) model provides empirically realistic mean-reverting volatility forecasts within a coherent and internally consistent, yet simple, modelling framework.

In order to define the GARCH class of models, let's consider the decomposition of s_t into the one-step-ahead conditional mean, $\mu_{t|t-1} \equiv E\,(s_t|\mathcal{F}_{t-1})$ and variance $\sigma_{t|t-1}^2 \equiv Var\,(s_t|\mathcal{F}_{t-1})$:

$$s_t = \mu_{t|t-1} + \sigma_{t|t-1} z_t \tag{13}$$

where $z_t \sim i.i.d.; E(z_t) = 0$ and $Var(z_t) = 1$. The GARCH(1,1)[9] model for the conditional variance is then defined by the recursive relationship:

$$\sigma^2_{t|t-1} = \omega + \alpha\varepsilon^2_{t-1} + \beta\sigma^2_{t-1|t-2} \tag{14}$$

where $\varepsilon_t = \sigma_{t|t-1} z_t$, and the parameters are restricted to be non-negative, $\omega > 0; \alpha, \beta \geq 0$, in order to ensure that the conditional variance remains positive for all realizations of the z_t process. As such, our fourth forecast, h_{4t}, of the conditional variance of s_t would be $\sigma^2_{t|t-1}$.Given that the heteroskedastic nature of financial time series has been confirmed by numerous empirical studies over the last decade[10], the generalized autoregressive conditional heteroskedastic process (GARCH) has been found to be superior for modelling financial asset returns, since they allow the variance to change over time by considering a long term memory contemporaneously.

4 Empirical Results and Discussion

This section will present all the results attained through the empirical measures presented in the last one. While presenting the regression results we will also give a detailed analysis of the values obtained for the risk premia and convenience yields for CO_2 allowances.

Initial predictions pointed out that futures prices should be able to forecast expected spot prices. In the following we present the results attained with the measure of risk premia on the CO_2 allowances market used and described above by equation (5).

The evolution of the risk premia between CO_2 spot prices and futures of maturity December 2006 to December 2012 for the EEX market (the first two plots) and between CO_2 spot prices and futures of maturity December 2005 to December 2014 for the ECX market (the last two plots), with a plot for each of the Phases, and market, under analysis: I and II.

Figure 2 (see appendix) allows us to infer about the time varying nature of the risk premium

[9] The model could be extended to higher order GARCH(p,q) models simply by including additional lagged squared innovations and/or conditional variances on the right-hand-side of equation (14). But the GARCH(1,1) fitted just well to our purposes and is suported by the findings of, for example, Figlewski (1997) of GARCH(1,1) superiority confined to stock market and its volatility forecasting.

[10] Also, our summary statistics of the data indicated this heteroscedasticity presented in all return series.

in EUAs in Germany and France. While it varies between futures contracts, figure 2 also points out that future contracts of all maturities seem to fluctuate together through time.

Basically, for Phase I contracts the variation of the risk premium is higher during the first quarter of 2006, while being higher at the end of quarter 2, beginning of quarter 3, for Phase II contracts. We may also observe the lower values for the risk premium in Phase I which occurred at the beginning of quarter 2 of 2006 and from quarter 1, 2007 onwards, for the reasons already pointed out before.

As a result of the financial worldwide crisis, in Phase II CO_2 futures contracts the minimum values were reached at the end of quarter 4, 2008 and the start of quarter 1, 2009. Despite this crisis, we should take into account that in January 2008, the European Comission has extended the scope of the EU allowance trading system to other sectors such as aviation and petrochemicals by 2013, confirming its functioning for Phase III until 2020. This has probably also contributed to the start of the decrease in prices and therefore the risk premium. After 2009, the risk premium for both EEX and ECX remained relatively stable and between 0 and 5, as futures contracts also approach their maturity.

In sum, allowances risk premiums are higher for the pre Kyoto protocol contracts compared to those of Phase II. This indicates that the degree of uncertainty decreased port-Kyoto negotiations and, therefore, increasing efficiency of the EU ETS allowances, which allow the incorporation of more information into prices, and investors increased rationality, through agents learning in the course of time.

Moreover, the sign of the risk premium (positive for most of the sample period) indicates that expected spot prices are lower than the forward price, which implies that day-ahead markets for CO_2 in both markets are in *normal contango*[11]. The exception is the beginning of 2009, but for the reasons already pointed out before this should come at no surprise. This results contradicts the findings of Daskalakis and Markellos (2009), while being in direct agreement with the results obtained by Chevallier (2010) for the French EU ETS market. Also, CO_2 allowances risk premiums vary in magnitude across delivery periods for Phase II contracts, while being very similar for Phase I contracts.

[11] We mentioned previously that we are considering $\pi = -FP$.

In table 2 (see appendix), descriptive statistics results for the risk premium calculated using (5) are presented. For both markets, the average risk premium is positive for all futures contracts analyzed.

Results confirm that mean risk premium and variance are strictly higher for Phase I contracts than for Phase II. This should come at no surprise given that period 1 spot allowances prices appeared in an experimental phase as mentioned previously.

In order to test the relation between risk premium and time-to-maturity equation (6) was estimated and plotted in figure 3 (see the appendix). This figure plots the risk premium by time-to-maturity in days for each of the futures maturity contracts under analysis (one for each), where the first one's are for the EEX market and the last for the ECX market. As evident by these plots, the higher the time to expiration, the higher the risk premium in EEX and ECX markets, thus contradicting the findings of Benth et al. (2008) and favouring those of Chevallier (2010). As such, the Samuelson effect is not verified in CO_2 allowances markets.

As evidenced by the plots, the β and δ coefficients of equation (6), which determine the relationship between risk premia and time-to-maturity, are both positive and statistically significant[12], implying that the basis variance decreases as contracts arrive close to maturity (Chevallier, 2010).

We move on presenting the results of the risk premium regression equation (8) on the volatility of the spot CO_2 and on the convenience yield, as estimated by equation (3). Table 3 (please see the appendix) presents the results obtained using the volatility forecast of equation (14), meaning the GARCH(1,1) volatility estimates for the spot price of CO_2 allowances. In the following we will evaluate how the variance of spot prices and yields improve the forecast performance of futures premium.

Volatility of spot CO_2 prices has a significant negative sign, thus influencing negatively the risk premium. The convenience yield appears to have a positive and statistically significant relation with the risk premium for Phase I contracts, and some of Phase II, in the EEX market, but negative for Phase I contracts in the ECX market, negative and not statistically significant for FutDec08 and FutDec10 in the EEX market, respectively. This may be attributed to the

[12] Results will be provided upon request.

newness of the market, and our results contradict those of previous theories (Schwartz, 1997; Wei and Zhu, 2006).

With respect to volatility, results point for opposite evidence when compared to previous empirical findings (Considine and Larson, 2001; Chevallier, 2010), but with respect to the convenience yield, the effect of this explanatory variable on the risk premium can be at best described as mixed for the Kyoto period in the EEX market, while being strictly positive for Phase II contracts in the ECX market. As such, results are sensitive to the market under analysis and to the data span considered. We should emphasize the fact that Chevallier obtained a positive influence of variance on allowances risk premium when regressing the risk premium on the variance and skewness of the spot, thus contradicting the empirical findings of Bessembinder and Lemmon (2002). However, data used by these author's only covers the period February 26, 2008 to April 15, 2009.

For the contracts FutDec07 and FutDec08, this simple empirical model is able to explain a significant portion of variation in the estimated risk premium. The adjusted R square is 0.59 and 0.62 for the EEX market, while being 0.82 and 0.59 for the ECX market, respectively. For the other contracts under analysis, this simple model is able to explain only a small portion, where $0.23 < R^2 < 0.38$ for EEX and $0.04 < R^2 < 0.56$ for the ECX market. Still, these results are consistent with other risk premium regressions results for other financial and commodity markets (see Wei and Zhu, 2006, for example).

For comparison purposes, we also used other volatility forecasts for the spot return CO_2 allowances whose estimates are presented in table 4 (see appendix). We have only presented results for the EEX market, given that the main conclusions were very similar[13]. As evident, even using different volatility forecasts the main results remain unchanged, and thus results are independent of the volatility forecast used.

Using daily squared returns volatility proxy, estimates for the spot volatility coefficient (β_1) are lower, still statistically significant, than those produced by the GARCH(1,1). Similar conclusions are taken when we compare results attained using Risk Metrics and Rolling Window approaches. As such, the negative influence of spot allowances volatility on the risk premium

[13] Results for the ECX market will be provided upon request.

is even more negative when GARCH(1,1) forecasting measure is used.

As for the R^2 values, these improve for Phase II contracts using Risk Metrics and Rolling Windows, as compared to those of GARCH(1,1), while being lower for daily square returns. As such, given that this model is only able to explain a small portion, other variables should be added to this simple model in order to see if results improve. Chevallier (2010) suggests a positive influence of spot price skewness, which should be taken as an alternative specification.

At the moment, we have said that Phase I contracts were much more volatile than Phase II Futures, which was then confirmed with empirical results. This fact may be attributed to the experimental stage at which Futures maturing on December 2006 and 2007 were, because Futures and spot allowances on these markets became a reality only after 2005, and thus it should come at no surprise this type of results.

In sum, there exists a negative influence of spot price volatility on risk premium (favouring Bessembinder and Lemmon, 2002, results for electricity markets), which are independent of the volatility proxy used in risk premium regressions. As for the convenience yield impact we may say that in general it has a positive influence. However, it was evident a negative influence of it on the risk premium for EEX FutDec08, although not statistically significant, and a negative significant influence for Phase I contracts in the ECX market. As for EEX we may attribute this behavioral change for December 2008 contracts to the transition stage and data span considered for this specific contract[14]. For the ECX market the learning process seems to have been more successful and therefore, the good market performance which allows us to agree with previous empirical findings about the positive influence of convenience yields on risk premium, although for a different commodity market (natural gas - Wei and Zhu, 2006).

We take one step forward now and proceed to the convenience yield regression estimates (equation (7)) using the specification in (14) for the spot CO_2 volatility. Results obtained through this regression are presented in table 5 (see the appendix), while figure 4 (see the appendix) plots the convenience yields in futures prices with delivery in November 2006 and November 2007 in the top panel, and with delivery in November 2008 through November 2014,

[14] Given spot erratic behavior at the beginning of 2008 we decided to work with data from March 2008 onwards.

for the EEX market (the first two plots) and for the ECX market (the last two plots).

At a first sight we can say that the series for the convenience yields estimates differ significantly for the pilot (2005-2007) and Kyoto period (2008-2012), as well as for the market under analysis.

Between quarter 4, 2005 and quarter 2, 2006 for the EEX market, the convenience yield is positive with values $0 < \psi < 10$, being observed a higher volatility, while being very close to zero for the ECX market. For the EEX market, when the news of over-allocation of allowances for the pilot period were published, the price shock on allowances also affected the convenience yield, where we see it decreasing until $-20 < \psi < -25$ values between quarter 2 and 4 of 2007. However, convenience yields with respect to ECX December 2007 futures contrasts have seen an increasing trend until reaching a value of 25. We should not forget that the CO_2 spot market (Bluenext) is separated from the Futures market (ECX) and this may be determining the results. While EEX was very sensitive to the transition period as may be observed, in the ECX market, futures, risk premium and convenience yields show a much more stable behavior during Phase I, although still affected by the banking restrictions which occur during the period.

In general, the persistence of the shock on convenience yields was very different during Phase II contracts. Despite being much lower during this period for both markets, we may say that it is even smaller the longer the contract expiration (FutDec11 and FutDec12 for EEX and FutDec13 and FutDec14 for ECX). Therefore, our results contradict those of Borak et al. (2006) for the same allowances market, due to the larger data span we have considered for the analysis performed throughout the paper.

Despite the similarity in the time series for convenience yields in either Phase, there exists different long-term reactions to the price shock. The persistence of negative convenience yields in Phase I period futures in the EEX market can be attributed to market participant's expectations on lower allocations for the commitment period (Borak et al., 2006). For a more detailed description of the relation between convenience yields and spot prices we refer to Borak et al. (2006). But this negative pattern is still evident for Phase II contracts in both markets although with lower values in magnitude terms. As such, this could be explained by market participant's uncertain expectations during the financial crisis, since we observe this negative persistence from quart 4, 2008 onwards. For the EEX market, this negative pattern started latter (Q1, 2009) which can be attributed to agents access to information. With this we mean that agents in the ECX market realized the impacts of the worldwide financial crisis earlier and felt it more intensively than those participants in the ECX market. As for quarters 2 and 3 in 2008, we may say that the higher the futures maturity date, the higher was the convenience yield.

The results that allowed the plots in figure 4 are presented in table 5. This table presents the coefficients and standard errors for the estimated regression (7) using the GARCH(1,1)[15] as estimator for the volatility of spot price returns. Each line refers to a future delivery date, going from December 2005 for the ECX market (December 2006 for the EEX) until December 2012, for both markets.

Both price and volatility are shown to significantly influence the convenience yield and the delivered signs are the same as those predicted by the theories with respect to prices, except those for FutDec07 and FutDec08 for the ECX market, and for FutDec08 for the EEX market. Therefore, the spot price is correlated with a positive sign to the convenience yield which becomes higher the longer the delivery period is.

The price volatility does not have a statistically significant impact on the convenience yield for Phase I contracts in the EEX market, while evidence turns out to be mixed for ECX. Despite this, for Phase II the negative and statistically sign for the coefficient on the spot volatility contradict the existent theories. Being the yield the dividend that we receive from holding a unit of the allowance, the negative sign relating spot volatility and convenience yield may indicate that investors see no privilege in holding the asset with respect to future periods, and as such care much more about the its short-term behavior. However, this result deserves a more special treatment and analysis.

In sum, and similar to Chevallier (2010) results, it seems that no linear relationship between spot and futures CO_2 allowances exist. Risk premium and convenience yield for both markets

[15] We have also used different volatility forecasts for this regression but the main conclusions, as taken for the risk premium (independence of the volatility forecast), remained and we skip this part. However, results will be provided upon request.

under analysis, are both affected negatively by the spot price volatility, and this opens room for a better understanding of the volatile behavior of EU ETS allowances, specially to the relation between volume, volatility and maturity of the futures contracts in EU ETS CO_2 allowances markets. Despite the fact we have provided information to energy market players that deal with risk management, or simply traders, for the need to hedge against a potential carbon price risk, it should be noticed that this market also depends on other energy fuels risk. Some of these aspects are already being object of a current research.

5 Conclusions

With this work we have contributed to the understanding of commodity pricing issues by measuring for CO_2 markets, two of the most important concepts in the storable commodity markets: the risk premium and the convenience yield. We therefore present regression estimation results related to both concepts and some statistical empirical properties relating both spot and futures allowances markets. We do that for two European EU ETS markets, in Germany (EEX) and France (ECX), using data covering the period 2005 - 2009.

Our results indicate that the convenience yield and risk premium are measurable and economically significant, being their determination not completely consistent with previous economic theory results, when tested for the allowances markets. Results are showed to be Phase, market and data span dependent, and therefore, can only be generalized with exceptions.

Empirical findings also indicate that there is a negative influence of spot CO_2 spot volatility on both the risk premium and convenience yield, independently of the volatility forecast used. Moreover, it is found that day-ahead markets for CO_2 are in normal contango and that the risk premium varies in magnitude across delivery periods.

The risk premium was found to vary positively with time-to-maturity, but the convenience yield affects it positively with significance only in the ECX, Phase II contracts. As such, results depend on the market and data span considered.

The persistence of negative convenience yields in Phase I futures was attributed to agents expectations, while these negative convenience yield for Kyoto period futures could be explained by the uncertainty faced by investors during the financial crisis period. But in general, convenience yield for allowances is positively related to the spot CO_2 return while negatively to the spot volatility. Given these results, we can even say that investors may see no privilege in holding the asset with respect to future period, being this a result that deserves a more special treatment together with a deeper analysis onto the volatility-volume-maturity relation, and the influence of fuels onto allowances markets.

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Table 1: **D**escriptive Statistics of spot prices and futures price contracts, both in logarithmic returns for EEX and ECX markets

EEX Series	obs.	mean	variance	skewness	kurtosis
Spot CO2	547	-1.125	8.200	0.050	10.426
FutDec06	295	-0.357	5.167	-0.404	30.829
FutDec07	547	-1.124	6.690	-0.856	11.798
FutDec08	176	-0.042	3.842	-0.752	15.220
FutDec09	390	-0.038	3.170	-0.437	16.451
FutDec10	390	-0.031	3.088	-0.486	16.465
FutDec11	390	-0.025	3.039	-0.598	17.283
FutDec12	390	-0.018	2.940	-0.574	16.380
ECX Series	obs.	mean	variance	skewness	kurtosis
Spot CO2	660	0.044	4.045	0.671	45.072
FutDec05	154	0.132	2.831	-1.811	12.494
FutDec06	408	-0.223	4.864	-0.292	44.226
FutDec07	660	-0.918	7.423	-0.821	18.152
FutDec08	174	0.110	2.944	-1.558	10.310
FutDec09	385	-0.009	3.353	-1.718	20.844
FutDec10	385	-0.002	3.322	-1.660	20.104
FutDec11	385	0.005	3.335	-1.600	18.576
FutDec12	385	0.011	3.404	-1.564	16.965

Spot refers to EEX and ECX CO_2 Spot prices, FutDec05 to FutDec12 refer to EEX and ECX December 2005 to 2012 CO_2 Futures contracts; obs. stand for the number of observations. The rest of the variables are the standard ones.

Table 2: **D**escriptive Statistics for the risk premium of futures maturities from December 2005 through December 2014 for EEX and ECX

EEX Series	obs.	mean	variance	skewness	kurtosis
FutDec06	293	11.294	5.855	0.023	1.906
FutDec07	545	11.253	10.389	0.300	1.621
FutDec08	174	3.679	3.432	0.588	3.648
FutDec09	389	7.099	3.421	0.660	3.827
FutDec10	389	7.593	3.407	0.716	3.960
FutDec11	389	8.100	3.402	0.777	4.082
FutDec12	389	8.623	3.400	0.841	4.172
ECX Series	obs.	mean	variance	skewness	kurtosis
FutDec05	153	1.694	2.673	0.260	4.045
FutDec06	407	1.700	5.760	-0.275	2.357
FutDec07	659	-9.590	10.336	-0.047	1.518
FutDec08	173	6.726	3.704	-0.910	2.980
FutDec09	384	5.210	6.025	0.324	1.580
FutDec10	384	5.839	6.183	0.326	1.584
FutDec11	384	6.596	6.321	0.326	1.587
FutDec12	384	7.621	6.461	0.318	1.611
FutDec13	384	8.958	6.620	0.389	1.679
FutDec14	384	10.072	6.628	0.402	1.730

FutDec05 to FutDec14 refer to EEX and ECX December 2005 to 2014 CO_2 Futures contracts; obs. stand for the number of observations. The rest of the variables are the standard ones.

Table 3: **R**isk premium determination for EEX and ECX EUAs of maturity December 2005 through December 2014 - GARCH(1,1)

	Contract	β_0	β_1	β_2	R^2	N
EEX data: equation (8) results						
Phase I	FutDec06	14.2***	-9.45***	3.29***	0.319	293
		(0.474)	(0.944)	(0.714)		
	FutDec07	20.5***	-16.5***	4.34***	0.597	545
		(0.606)	(0.748)	(0.58)		
Phase II	FutDec08	14.6***	-24.0***	-1.3	0.62	174
		(0.471)	(1.47)	(0.818)		
	FutDec09	10.6***	-18.9***	4.85***	0.233	389
		(0.821)	(2.31)	(1.03)		
	FutDec10	10.0***	-17.1***	4.59	0.27	389
		(0.872)	(2.36)	(0.687)		
	FutDec11	9.98***	-15.3***	4.56***	0.336	389
		(0.847)	(2.31)	(0.487)		
	FutDec12	12.1***	-15.9***	4.05***	0.388	389
		(0.779)	(2.24)	(0.361)		
ECX data: equation (8) results						
	Contract	β_0	β_1	β_2	R^2	N
Phase I	FutDec05	2.43***	-40.33*	0.90*	0.035	153
		(0.59)	(20.77)	(0.53)		
	FutDec06	6.28***	-84.37***	-0.99***	0.199	407
		(0.48)	(10.62)	(0.15)		
	FutDec07	2.33***	-92.09***	-1.12***	0.818	659
		(0.38)	(9.46)	(0.02)		
Phase II	FutDec08	9.58***	-169.39***	6.55***	0.588	173
		(0.86)	(24.67)	(0.88)		
	FutDec09	9.79***	-246.61***	6.90***	0.361	384
		(0.99)	(27.88)	(0.85)		
	FutDec10	8.82***	-210.13***	5.92***	0.389	384
		(1.06)	(29.10)	(0.62)		
	FutDec11	9.46***	-195.08***	4.82***	0.419	384
		(1.02)	(29.21)	(0.45)		
	FutDec12	11.87***	-200.49***	3.91***	0.440	384
		(0.94)	(29.03)	(0.34)		
Phase III	FutDec13	14.17***	-153.08***	3.37***	0.414	374
		(0.91)	(31.16)	(0.29)		
	FutDec14	14.46***	-96.83***	3.62***	0.561	374
		(0.79)	(27.27)	(0.21)		

The model used is that of equation (8) using specification (14) for the spot volatility: $\pi_t = \beta_0 + \beta_1\sigma^2_{s,t} + \beta_2\psi_t + \varepsilon_t$.. *,**,*** indicate significance at level 10%, 5% and 1%, respectively. N stands for the number of observations available. Values in parenthesis are standard errors.

Table 4: Determination of the risk premium for EEX EUAs of maturity December 2006 through December 2012 - Daily Square Returns; Rolling Window; Risk Metrics

	Contract	β_0	β_1	β_2	R^2	N
EEX data: daily square returns for spot volatility						
Phase I	FutDec06	10.7***	-0.004**	4.21***	0.099	293
		(0.357)	(0.001)	(0.814)		
	FutDec07	9.72***	-0.009***	9.01***	0.265	545
		(0.444)	(0.002)	(0.726)		
Phase II	FutDec08	7.66***	-0.062**	2.08	0.0693	174
		(0.268)	(0.021)	(1.23)		
	FutDec09	5.07***	-0.0848***	6.57***	0.143	389
		(0.347)	(0.0192)	(1.05)		
	FutDec10	4.84***	-0.077***	5.82***	0.204	389
		(0.374)	(0.019)	(0.686)		
	FutDec11	5.36***	-0.068***	5.37***	0.285	389
		(0.354)	(0.0185)	(0.482)		
	FutDec12	7.45***	-0.071***	4.63***	0.334	389
		(0.314)	(0.0182)	(0.364)		
EEX data: Rolling Window for spot volatility						
	Contract	β_0	β_1	β_2	R^2	N
Phase I	FutDec06	11.9***	-0.0414***	3.25***	0.162	293
		(0.42)	(0.00794)	(0.807)		
	FutDec07	16.2***	-0.108***	4.67***	0.485	545
		(0.566)	(0.00664)	(0.671)		
Phase II	FutDec08	16.8***	-1.84***	-2.07***	0.691	174
		(0.513)	(0.0954)	(0.744)		
	FutDec09	9.78***	-0.603***	3.07***	0.379	389
		(0.49)	(0.046)	(0.943)		
	FutDec10	9.91***	-0.571***	2.14***	0.36	389
		(0.617)	(0.0534)	(0.717)		
	FutDec11	9.67***	-0.495***	2.94***	0.389	389
		(0.618)	(0.0548)	(0.532)		
	FutDec12	10.9***	-0.459***	2.9***	0.415	389
		(0.55)	(0.0548)	(0.408)		
EEX data: Risk Metrics for spot volatility						
	Contract	β_0	β_1	β_2	R^2	N
Phase I	FutDec06	11.5***	-0.029***	3.68***	0.154	293
		(0.389)	(0.006)	(0.797)		
	FutDec07	14.5***	-0.0745***	5.86***	0.449	545
		(0.526)	(0.005)	(0.67)		
Phase II	FutDec08	13.7***	-1.14***	-1.41***	0.678	174
		(0.37)	(0.061)	(0.75)		
	FutDec09	8.95***	-0.519***	4.06***	0.355	389
		(0.457)	(0.042)	(0.941)		
	FutDec10	8.84***	-0.479***	3.21***	0.351	389
		(0.543)	(0.046)	(0.677)		
	FutDec11	8.88***	-0.423***	3.51***	0.388	389
		(0.544)	(0.471)	(0.5)		
	FutDec12	10.4***	-0.402***	3.26***	0.419	389
		(0.485)	(0.0469)	(0.382)		

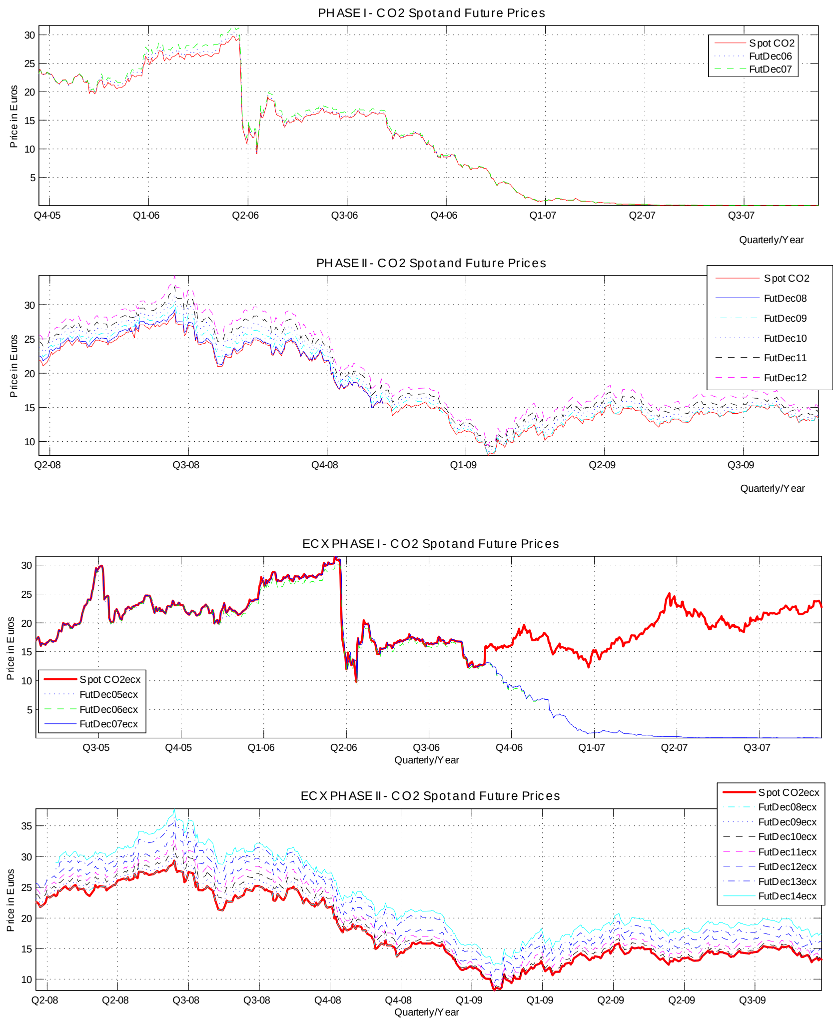
The model used is that of equation (8) using specifications (10), (11) and (12), respectively, for the spot volatility: $\pi_t = \beta_0 + \beta_1 \sigma_{s,t}^2 + \beta_2 \psi_t + \varepsilon_t$.. *,**,*** indicate significance at level 10%, 5% and 1%, respectively. Values in parenthesis are standard errors.

Table 5: Convenience yield regression results for EEX and ECX EUAs of maturity December 2005 through December 2012 - GARCH(1,1)

	Contract	β_0	β_1	β_2	R^2	N
EEX data: equation (7) results						
Phase I	FutDec06	-0.345***	0.0254***	0.074	0.11	293
		(0.109)	(0.0046)	(0.08)		
	FutDec07	-0.019	0.026***	-0.044	0.263	545
		(0.074)	(0.002)	(0.072)		
Phase II	FutDec08	0.332***	-0.0055	-0.597***	0.098	174
		(0.098)	(0.003)	(0.139)		
	FutDec09	0.204***	0.0064***	-0.624***	0.106	389
		(0.042)	(0.0015)	(0.109)		
	FutDec10	0.459***	0.006***	-0.624	0.106	389
		(0.042)	(0.0015)	(0.109)		
	FutDec11	0.54***	0.0215***	-1.76***	0.214	389
		(0.0828)	(0.0030)	(0.216)		
	FutDec12	0.254**	0.0363***	-2.12***	0.260	389
		(0.105)	(0.0038)	(0.273)		
ECX data: equation (7) results						
	Contract	β_0	β_1	β_2	R^2	N
Phase I	FutDec05	-0.65**	0.04***	10.83***	0.122	153
		(0.28)	(0.01)	(3.03)		
	FutDec06	1.55***	0.01	-4.62	0.006	407
		(0.43)	(0.02)	(3.82)		
	FutDec07	14.38***	-0.19**	-74.48***	0.025	659
		(1.92)	(0.08)	(18.87)		
Phase II	FutDec08	1.10***	-0.02***	-16.17***	0.372	173
		(0.11)	(0.00)	(1.71)		
	FutDec09	0.38***	0.02***	-14.84***	0.191	384
		(0.07)	(0.00)	(1.65)		
	FutDec10	0.67***	0.03***	-25.22***	0.256	384
		(0.09)	(0.00)	(2.25)		
	FutDec11	0.88***	0.03***	-35.30***	0.250	384
		(0.13)	(0.01)	(3.15)		
	FutDec12	0.67***	0.05***	-45.60***	0.247	384
		(0.17)	(0.01)	(4.16)		

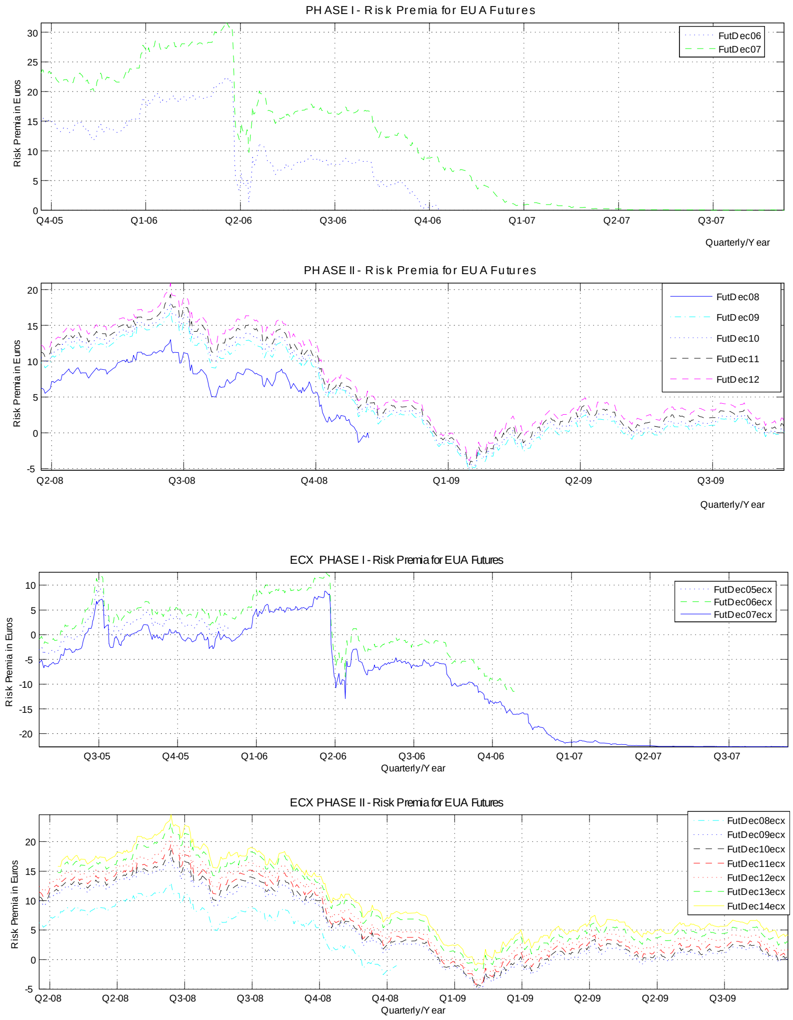
FutDec05 to FutDec12 refer to EEX and ECX December 2005 to 2012 CO_2 Futures Contracts. *,**,*** indicate significance at level 10%, 5% and 1%, respectively. N stands for the number of observations available. Values in parenthesis are standard errors. The model used is that of equation (7) using specification (14) for the spot volatility: $\psi_t = \beta_0 + \beta_1 s_t + \beta_2 \sigma_t^2 + \varepsilon_t$.

Figure 1: EUA spot prices and futures contracts for all delivery periods considered and for both markets and Phases (I and II). The upper two plots are for the EEX markets, the other ones for the ECX market.



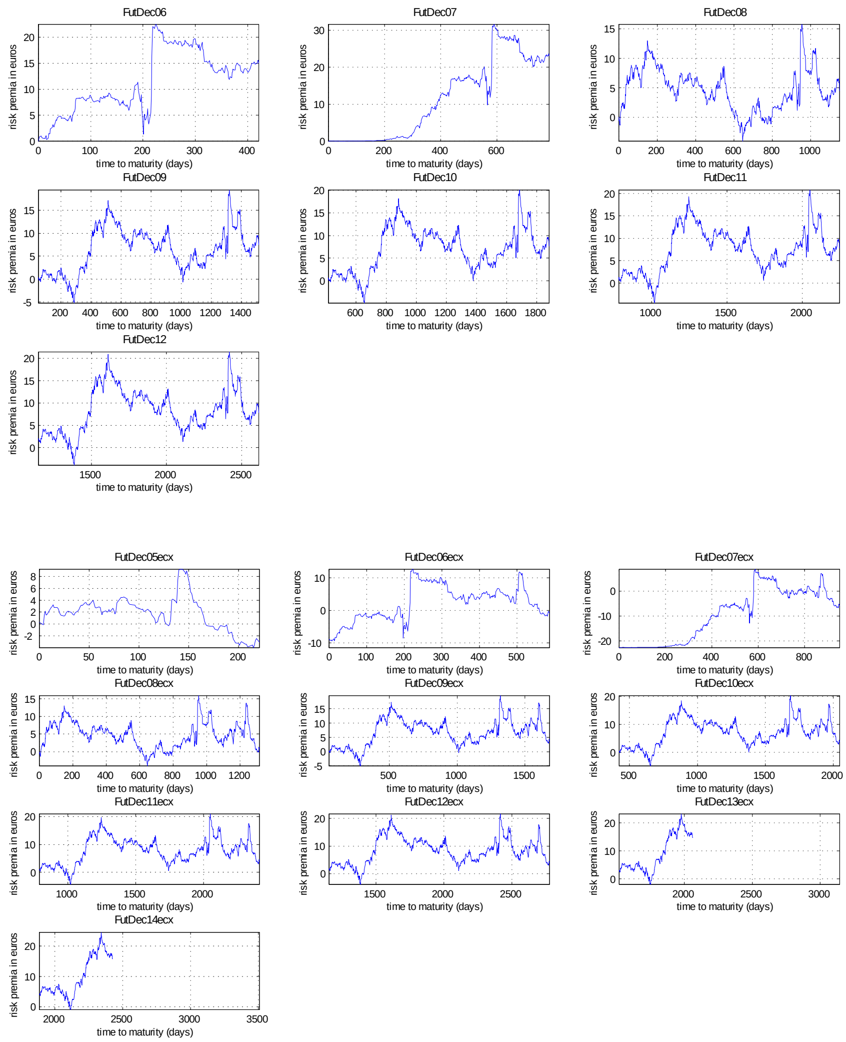
Spot refers to EEX and ECX CO_2 Spot prices, FutDec05 to FutDec14 refer to EEX and ECX December 2005 to 2014 CO_2 Futures contracts.

Figure 2: Risk premia for EEX and ECX futures contracts of maturity December 2005 through 2014 from May 2006 to October 2009.



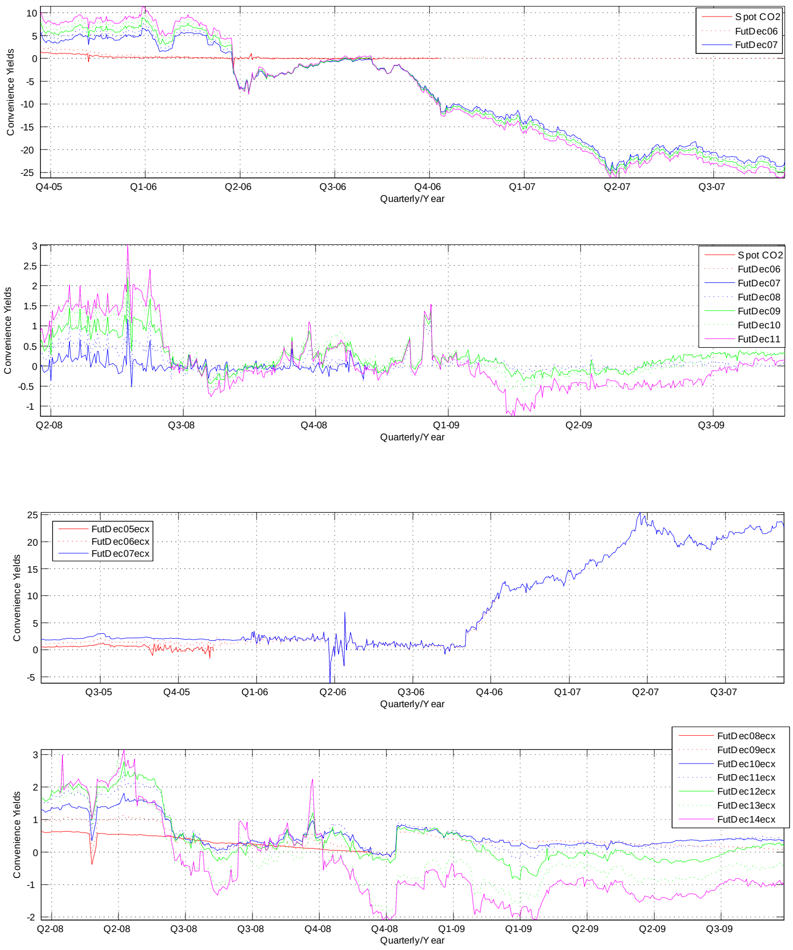
FutDec05 to FutDec14 refer to EEX and ECX December 2005 to 2014 CO_2 Futures Contracts.

Figure 3: Risk premium by time-to-maturity for each contract in the sample



FutDec05 to FutDec14 refer to EEX and ECX December 2005 to 2014 CO_2 Futures contracts.

Figure 4: Convenience yields in futures prices with delivery in Phase I and Phase II for the EEX (first two top panels) and ECX (two bottom panels).



Spot refers to EEX and ECX CO_2 Spot prices, FutDec05 to FutDec14 refer to EEX and ECX December 2005 to 2014 CO_2 Futures contracts.