The Relationship between Spot and Futures CO_2 Emission Allowance Prices in the EU-ETS[☆]

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Abstract

In this paper we investigate the relationship between spot and futures prices within the EU-wide CO_2 emissions trading scheme (EU-ETS). We conduct an empirical study on price behavior, volatility term structure and correlations in different CO_2 EU Allowance (EUA) contracts during the pilot trading and the first Kyoto commitment period. We find that for the pilot trading period (2005-2007) the market was initially in backwardation, while after the news of sufficiently high allocations, both allowance prices and convenience yields approached zero. On the other hand, futures contracts referring to the Kyoto commitment period were less affected by the price drop. Considering spot and allowance futures prices during Phase II (2008-2012), we find that the market has changed from initial backwardation to contango with significant convenience yields in futures contracts. We attribute this deviation from the cost-of-carry relationship to three main factors: low interest rate levels in the Eurozone; market participants' willingness to pay an additional premium for a hedge against rising prices in future periods, and, the increasing level of surplus allowances and banking during Phase II.

Keywords: CO_2 Emissions Trading, Commodity Markets, Spot and Futures Prices, Convenience Yields.
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1. Introduction

In January 2005 the advent of the EU-wide emissions trading scheme (EU-ETS) introduced emission allowances as a new class of financial assets. Since environmental policy has historically

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been a command-and-control type regulation where companies had to strictly comply with emission standards, the trading scheme indicates a shift in paradigms. The market not only requires regulated emitters to run an adequate risk management, it also provides new business development opportunities for market intermediaries and service providers like brokers or marketeers.

Under the Kyoto Protocol the EU had committed to reducing greenhouse gas (GHG) emissions by 8% compared to the 1990 level by the year 2012, while the proposed caps in the EU-ETS for 2020 represent a reduction of more than 20% of greenhouse gases. All combustion installations exceeding 20 MW are affected by the trading scheme including different kinds of industries like metal, cement, paper, glass, etc., as well as refineries or coke ovens. As of 2013, the EU-ETS includes over 11,000 installations, tht are collectively responsible for almost 50% of EU's CO_2 emissions. The EU-ETS comprises the world's largest GHG emissions trading system. Each participating country proposes a so-called National Allocation Plan (NAP) including caps on greenhouse gas emissions for power plants and other large point sources which must subsequently be approved by the European Commission. After an initial pilot trading period (2005-2007), in 2008 there were new allocation plans for each of the countries and the first Kyoto commitment trading period lasted from 2008 to 2012. The third trading period started in January 2013 and will last until December 2013.

Failure to submit a sufficient amount of allowances resulted in sanction payments of 40 EUR per missing ton of CO_2 allowances during the pilot period and 100 EUR in the second and third trading period. Hence, the carbon emission market forces companies to hold an adequate number of allowances according to their carbon dioxide output. As a consequence, participating companies face several risks specific to emissions trading. In particular, price risk (of fluctuating allowance prices) and volume risk (due to unexpected fluctuations in energy demand the emitters do not know ex ante their exact demand for EUAs) have to be considered. Naturally, market generic risks – like counterparty, operational, reputational, etc. – are also present. Participating companies may need to develop adequate risk management strategies as well as reliable models for the demand and for CO_2 allowance prices to reduce the risk of facing substantial sanction payments or possible high prices for purchasing additional CO_2 allowances. For a thorough discussion of this issue see e.g. Bokenkamp et al. (2005).

Clearly, to hedge these risks, next to monitoring the spot market, also derivative instruments such as options and futures contracts for carbon emission allowances will be of great interest to market participants. Since these participants face the decision when to sell surplus or buy additionally required permits, in particular the relationship between carbon spot and futures prices is of great interest. For other commodities like oil or agricultural products, the connection between spot and futures prices and the convenience yield has been investigated more thoroughly. For pricing contingent claims in commodity markets Gibson and Schwartz (1990) present a two-factor model using the spot price and the instantaneous convenience yield as factors. With respect to the relationship between spot and futures prices the literature finds some evidence on expected spot prices often exceeding the futures price of such assets (Bodie and Rosansky, 1980; Chang, 1985; Pindyck, 2001). This situation is called normal backwardation and was initially suggested by Keynes (1930). Wei and Zhu (2006) find economically significant convenience yield and risk premiums in the U.S. natural gas market. However, for electricity prices there is also some evidence that futures prices may exceed expected spot prices, see e.g. Bierbrauer et al. (2007), Botterud et al. (2010), Longstaff and Wang (2004) and Weron (2008), a situation called contango. Due to the peculiarity of the market for CO_2 emission allowances as well as the ambiguous results in different commodity markets, it seems worthwhile to compare the behavior of EUA spot and futures prices.

Since the official start of spot and futures trading in 2005, a high number of studies have investigated the price behavior of CO_2 spot or futures contracts, while usually less attention has been directed to the relationship between the two markets.

Paolella and Taschini (2008), Seifert et al. (2008) as well as Benz and Trück (2008) were among the first studies to provide an econometric analysis of the behavior of allowance prices and investigate different models for the dynamics of short-term spot prices. Paolella and Taschini (2008) conduct an econometric analysis of emission allowance spot market returns and suggest that the conditional dynamics of allowance returns can be approximated by a GARCH-type structure. Seifert et al. (2008) develop a theoretical stochastic equilibrium model in order to incorporate stylized facts of the European carbon market. Their findings suggest that discounted CO_2 prices should possess the martingale property and that carbon prices exhibit a time- and price-dependent volatility structure. Benz and Trück (2008) apply AR-GARCH and regime-switching models to describe the dynamics of Phase I emission allowance spot prices. Their results support the adequacy of the considered models capturing characteristics like skewness, excess kurtosis and in particular different phases of volatility behavior in the returns.

Another stream of literature is more concerned with the price drivers of allowance prices. Chevallier (2009a) examines the empirical relationship between the returns on carbon futures and changes in macroeconomic conditions and documents that carbon futures returns may be weakly forecast on the basis of two variables from the stock and bond markets, i.e. equity dividend yields and the 'junk bond' premium. Hintermann (2010) examines price drivers of EUAs during the first phase of the EU ETS, in particular the extent to which variation in prices can be explained by marginal abatement costs. Bredin and Muckley (2011) examine the extent to which fundamental factors, like economic growth, energy prices and weather conditions, determine the EUA futures prices during the period 2005-2009. Chevallier (2011) suggests that yearly compliance events, and growing uncertainties in post-Kyoto international agreements, may explain the instability in the volatility of carbon prices. Gronwald et al. (2011) investigate the dependence structure between EUA futures returns and those of other commodities, equity and energy indices and find significant positive correlations between the considered markets. Conrad et al. (2012) model the adjustment process of EUA prices to the releases of announcements at high-frequency. They find that decisions of the European Commission on National Allocation Plans have a strong and immediate impact on EUA prices and that EUA prices increase in response to better than expected news on the future economic development.

A number of studies provide insights on the pricing of derivative instruments for emission allowances. Daskalakis et al. (2009) develop a framework for the pricing and hedging of intra-phase and inter-phase derivatives contracts and find some evidence that market participants adopt standard no-arbitrage pricing. Carmona and Hinz (2011) develop a risk-neutral reduced-form model for allowance futures prices and show how to price European call options written on these contracts. Chesney and Taschini (2012) use dynamic optimization models to endogenously generate the price dynamics of emission permits under asymmetric information, allowing inter-temporal banking and borrowing. The model is solved numerically and a closed-form pricing formula for European-style options is derived. In an empirical study, Isenegger et al. (2013) evaluate different models for the pricing of exotic option contracts based on observed carbon spot and futures prices. Approaches considered in their study include a standard GARCH model, a t-GARCH model as well as a mean-reverting jump diffusion model. Based on observed market prices the authors suggest that the mean-reverting jump diffusion model provides the best fit to the analyzed option instruments.

There is also a number of studies on price discovery in CO_2 spot and futures markets. Uhrig-Homburg and Wagner (2009), analyzing data from the pilot trading period find that futures markets expiring in December 2006 and 2007 lead the price discovery process of CO2 emission certificates. On the other hand, Milunovich and Joyeux (2010), also examining data from Phase I suggest that CO_2 spot and futures markets share information efficiently and contribute to price discovery jointly. These results are confirmed by Niblock and Harrison (2012) who also find that spot and forward prices both contribute jointly to price discovery in carbon markets during the pilot trading period. Gorenflo (2013) conducts a impulse response analysis and finds that the futures market has a leadership position against the spot market and contributes the most to price discovery. Finally, Benz and Hengelbrock (2008) analyze price discovery between different exchanges ECX and Nord Pool using intraday data. They suggest that for EUA futures contracts with maturity in December 2005 and 2006 both exchanges contributed to price discovery. On the other hand, for contracts maturing in December 2007 and December 2008, they find that the more liquid market ECX is leading the less liquid Nord Pool market.

Most relevant to the topic of this paper is previous empirical research on the relationship between spot and futures prices, convenience yields and deviations from the cost-of-carry relation in emissions allowance markets. Milunovich and Joyeux (2010) examine the issues of market efficiency in the EU carbon futures market during the pilot trading period. The authors find that none of the carbon futures contracts examined are priced according to a cost-of-carry model. However, futures contracts referring to the pilot trading period form a stable long-run relationship with the spot price and can be considered as risk mitigation instruments. Interestingly, Uhrig-Homburg and Wagner (2009), also examining EUA prices during the pilot trading period, find contradictory results: examining the relationship between EU carbon spot and futures markets during Phase I, the authors suggest that after an initial period of rather noisy pricing, the cost-of-carry model is largely found to hold. They report that while the convenience yield is not consistent over time and temporary deviations from the cost-of-carry linkage may exist they generally vanish after only a few days. Unfortunately, the results of these two studies are limited to the first trading period where banking of allowances from the pilot to the later Kyoto commitment period was not allowed. Therefore, results on the cost-of-carry relationship between spot and futures contracts might be questionable, in particular when looking at inter-period relationships. Chevallier (2009b) investigates the modeling of the convenience yield in the EU-ETS for Phase II, using daily and intra-daily measures of volatility. The author finds a non-linear relation between spot and futures prices and suggests that the dynamics of the observed convenience yield can be best described by a simple autoregressive process. Madaleno and Pinho (2011) examine EUA spot and futures prices from an ex-post perspective also for the first Kyoto commitment period and find evidence for a significant negative risk premium (i.e. a positive forward premium) in the market. They also find a positive relationship between risk premiums and time-to-maturity of the futures contracts. More recently, Gorenflo (2013) suggests that the cost-of-carry hypothesis between spot and futures prices holds for the trial period while for the Kyoto commitment period there are deviations from the cost-of-carry relationship. Finally, Chang et al. (2013), based on the cost-of-carry model, examine the properties of convenience yields for CO2 emissions allowances futures contracts with maturities from December 2010 to December 2014. The authors suggest that convenience yields for CO_2 emissions allowances exhibit a time-varying trend, are mean-reverting, while the standard deviation in the convenience yield declines with an increase in time-to-maturity.

This paper, to our best knowledge, provides the first study to consider the relationship between carbon emission spot and futures prices considering both the pilot trading from 2005-2007 as well as the entire first Kyoto commitment period from 2008-2012. Our goal is to provide a thorough analysis of the spot-futures price relationship in the EU-ETS, also in comparison to other commodity markets. We investigate correlations between spot and futures contracts, as well as deviations from the cost-of-carry relationship, convenience yields and the volatility term structure for these two periods. We relate our results to general concepts of commodity markets such as backwardation and contango markets. Due to changing regulations on the banking of emission allowance contracts between Phase I and Phase II, we examine how these changes have impacted on the observed spot-futures relationship. By investigating these issues, we also provide insights into participants' evaluation of risks in the market, their reaction to price shocks and their assumptions on future supply and demand of permits during the second Kyoto commitment period.

The remainder of the paper is organized as follows. Section 2 reviews general concepts about the relationship between spot and futures prices in commodity markets and explains the ideas of normal backwardation or contango markets as well as the so-called Samuelson effect. It further illustrates the idea of the convenience yield as the benefit to the holder of commodity inventory. Section 3 provides an empirical analysis on CO_2 spot and futures prices. We investigate the connection between EUA spot and futures prices and the convenience yield both for the pilot and first Kyoto commitment period. Section 4 concludes and gives suggestions for future work on the topic.

2. Commodity Spot and Futures Markets

An appropriate approach in specifying EUAs might be their consideration as a factor of production, see e.g. Fichtner (2004); Benz and Trück (2006). Similar to other commodities, they can be 'exhausted' for the production of CO_2 and after their redemption they are removed from the market. Since a competitive commodity market is subject to stochastic fluctuations in both production and consumption, market participants will generally hold inventories. For emission allowances, producers may hold such inventories to reduce the costs of adjusting production over time or to avoid stockouts. Unlike for other factors of production, the amount of allowances has to match the actual production figure of the preceding calendar year only by April 30 of the next year. However, examining appropriate financial models for CO_2 emission allowances, the obvious parallels to a factor of production motivate the idea to adopt approaches from commodity markets rather then using typical financial models for asset pricing. Hence, in this section we will briefly

Table 1: Description of market situation based on the relationship between (expected) spot and futures price.

Market Situation	**Relation between (expected) spot and futures price**
Backwardation	$F_{t,T} \leq S_t$
Normal Backwardation	$F_{t,T} \leq E_t(S_T)$
Contango	$F_{t,T} > S_t$
Normal Contango	$F_{t,T} > E_t(S_T)$

review some features of commodity markets with focus on the relationship between the spot and futures markets.

2.1. Backwardation and Contango

The futures market is said to exhibit *backwardation* when the futures price $F_{t,T}$ is less than or equal to the current spot price S_t; it exhibits *normal backwardation* when the futures price is less than or equal to the expected spot price $E_t(S_T)$ at time T. On the other hand, the term *(normal) contango* is used to describe the opposite situation, when the futures price $F_{t,T}$ exceeds the (expected) spot price at time T. Table 1 summarizes the four different situations, see e.g., Hull (2005) or Pindyck (2001).

The differences between spot and futures prices can be explained by a typical insurance contract: in the (normal) backwardation case the producers are buying insurance against falling prices, whereas in the contango case, consumers buy insurance against rising prices. The theory postulates that commodity futures markets usually exhibit backwardation and tend to rise over the life of a futures contract. Initially suggested by Keynes (1930) and Hicks (1946), the idea of backwardation assumes that hedgers tend to hold short positions as insurance against their cash position and must pay speculators a premium to hold long positions in order to offset their risk. Thus, observed futures prices $F_{t,T}$ with delivery at time T are often below the expected spot price $E_t(S_T)$. The notion of normal backwardation is equivalent to a positive risk premium since the risk is transferred to the long position in the futures contract; likewise normal contango is equivalent to a negative risk premium. Formally the *risk premium* is defined as the reward for holding a risky investment rather than a risk-free one. In other words, the risk premium is the difference between the expected spot price, which is the best estimate of the going rate of the asset at some specific time in the future, and the forward price, i.e. the actual price a trader is prepared to pay today for delivery of the asset in the future (Botterud et al., 2010; Diko et al., 2006; Pindyck, 2001; Weron, 2008). Note, that in the financial mathematics literature yet a different notion is used. The *market price of risk* (often denoted by λ) is defined as the difference between the drift in the original 'risky' probability measure P and the drift in the 'risk-neutral' measure P^{λ} in the stochastic differential equation governing the price dynamics (Weron, 2006). The spot price forecast $E_t(S_T)$ is the expected value of the spot price at some future date with respect to P, while the forward price $F_{t,T}$ is the expected value of the spot price with respect to P^{λ}. If λ is positive then the risk premium is also positive, and vice versa.

Another interesting issue is the term structure of a commodity's forward price volatility. Investigating the issue, Samuelson (1965) found a typically declining term structure in the volatility of futures prices as maturity increases. This behavior is referred to as the *Samuelson effect* or as the *time-to-maturity effect*. The behavior is generally explained by the fact that the opinion of investors of a distant future environment, including the evaluation of distant futures prices, is only subject to minor changes in the near future. Hereby, it is assumed that only few of the parameters affecting the final level of the prices will change today. Hence, only minor effects can be expected for futures with long maturities. However, as the maturity date is approached, investors are clearly more sensitive to information that influences the level of the futures price at maturity.

2.2. Relating Spot and Futures Prices

Approaches for the valuation of forward and futures contracts can be conceptually divided into two groups (Fama and French, 1987). The first group suggests a risk premium to derive a model for the relationship between short-term and long-term prices. The second group is closely linked to the cost and convenience of holding inventories. In the following we follow the second approach and briefly illustrate the derivation of the convenience yield.

The convenience yield is usually derived within a no-arbitrage or cost-of-carry model which is based on considerations on a hedging strategy consisting of holding the underlying asset of the futures contract until maturity. Hereby, the long position in the underlying is funded by a short position in the money market account. Risk drivers determining the futures price in this case include the cost-of-storage for forwards on commodities, cost-of-delivery and interest rate risk. Differences between current spot prices and futures prices are explained by interest foregone in storing a commodity, warehousing costs and the so-called convenience yield on inventory. By assuming no possibilities for arbitrage between the spot and futures market, a formula for the convenience yield can be derived (Geman, 2005; Pindyck, 2001).

Assume that we hold one unit of emission rights at time t and the current spot price is S_t. Obviously there is no physical storage cost for holding an emission right. Hence, assuming the existence of a convenience yield, holding the emission right until T will pay us the stochastic return:

$$S_T - S_t + \gamma_{(T-t)}. \tag{1}$$

Hereby, $\gamma_{(T-t)}$ denotes the convenience yield for holding the emission right from t until T. Assume that at the same time we also short a futures contract written on the emission right with delivery in T. The return of this futures contract equals $F_{t,T} - S_T$. Note that there is no risk involved in the transactions and the total return is non-stochastic and should equal the return of a risk-free investment for the period $T - t$ times the current spot price of the emission right:

$$S_T - S_t + \gamma_{(T-t)} + F_{t,T} - S_T = (e^{r(T-t)} - 1)S_t. \tag{2}$$

Solving for $\gamma_{(T-t)}$ we get the following equation for the (capitalized) flow of marginal convenience yield (Pindyck, 2001):

$$\gamma_{(T-t)} = S_t e^{r(T-t)} - F_{t,T}. \tag{3}$$

The convenience yield obtained from holding a commodity can be regarded as being similar to the dividend obtained from holding a company's stock. It represents the privilege of holding a unit of inventory, for instance, to be able to meet unexpected demand. According to Pindyck (2001) the spot price of a commodity can be explained similar to the price of a stock: like the price of a stock can be regarded as the present value of the expected future flow of dividends, the price of a commodity is the present value of the expected future flow of convenience yields. Alternatively, one could argue that the convenience yield is the *residual* needed to align cost-of-carry commodity futures prices with observed market prices. The cost-of-carry model describes an arbitrage relation between the futures price, spot price and the cost of carrying the asset such that with zero cost of storage the cost-of-carry relationship can simply be expressed by:

$$F_{t,T} = S_t e^{r(T-t)} + \epsilon_{t,T} \tag{4}$$

Clearly, by comparing equation (3) and (4), one can see that the convenience yield simply equals the residual $\epsilon_{t,T}$ in the cost-of-carry model.

3. Empirical Results

3.1. The Data

For our analysis we use available market quotes from the European Energy Exchange (EEX) and European Climate Exchange (ECX) for the pilot trading period, while price data for the Kyoto commitment period is sourced from PointCarbon, one of the major data supplier for global gas, power and carbon markets. More precisely, data on Phase I spot prices os obtained from EEX, while EUA futures prices during the pilot trading period are from the more liquid ECX. The entire data for the Kyoto commitment period (spot and futures prices) is obtained from PointCarbon. For the pilot trading period we consider spot and futures prices from October 4, 2005 to November 29, 2007, for the Kyoto commitment period for the period April 8, 2008 – December 31, 2012. Spot contracts for EU emission allowances have a contract volume of 1 ton CO_2 and are quoted in EUR with a precision of two decimal points. For the pilot trading period beginning on January 1, 2005 we consider 2006, 2007 and 2008 futures contracts, for the first Kyoto commitment period beginning on January 1, 2008 we consider 2008, 2009, ..., 2012 futures, and for the second Kyoto commitment period beginning on January 1, 2013 we consider 2013, 2014 and 2015 futures contracts. The contract volume amounts to 1000 tons of CO_2 and the contracts expire on the last business day in November (for the EEX futures) or on the last business day in December (for the ECX futures). For every futures contract a settlement price, in accordance with the current spot market price is established on a daily basis. According to a daily profit and loss balancing (variation margin), the change in the value of a futures position is credited to the trading participant or debited from her in cash. For both markets, delivery of the EU emission allowances is carried out up to two business days after maturity of the contracts. For the risk free rates we use daily European Central Bank (ECB) quotes for AAA-rated euro area central government bonds. These quotes are available for bonds with a maturity from three months up to 5 years. To match the yields for different time horizons until maturity of the considered futures contracts we use linear interpolation. Note that unlike the studies by Madaleno and Pinho (2011); Gorenflo (2013); Chang et al. (2013), where an assumption about a constant average risk-free rate is made, we use the actually observed daily rates for each maturity.

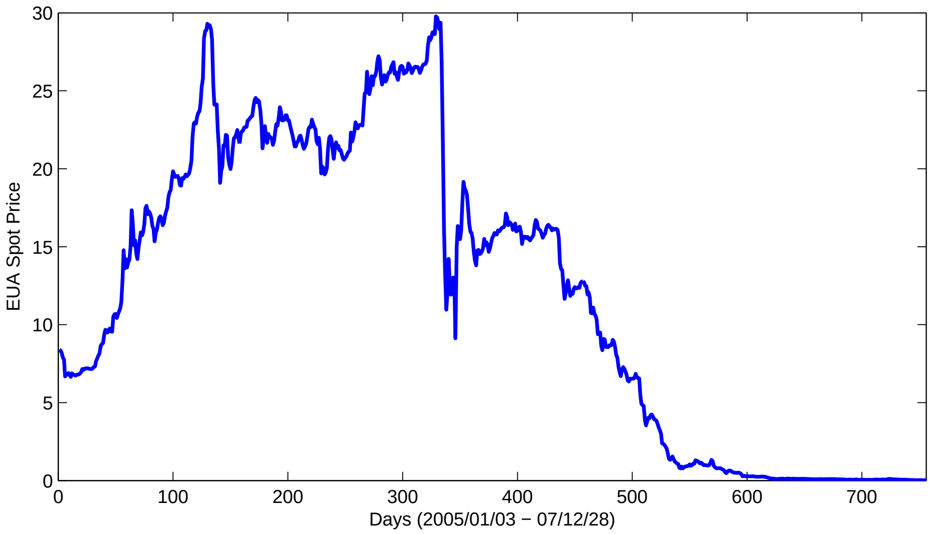

Figure 1: EUA spot price for the pilot trading period from January 3, 2005 to December 28, 2007. Note, that the time scale uses business days, i.e. there are approximately 250 observations per year.

3.2. The Pilot Trading Period

We start with an analysis of the relationship between spot and futures prices for the pilot trading period. While spot trading started already in January 2005, when the EU-wide CO_2 emissions trading system entered into operation, futures contracts were traded only since October 2005. Figure 1 displays CO_2 emission allowance spot prices for the pilot trading period from January 3, 2005 till December 28, 2007. At the commencement of trading, spot prices initially fell due to a quite mild climate and high supply of wind energy from Scandinavia and northern Germany. However, from February onwards an extreme cold snap and constant high UK gas and oil prices, compared to relatively low coal prices, led to a significant price increase within the next months. This effect was boosted by an extremely dry summer in the southwest of Europe. Especially in Spain, due to high temperatures and absence of rainfall, hydro-storage plants could not be fully utilized. Additionally, the lack of cooling water for nuclear power plants led to a higher power plant utilization and therefore increased the demand for CO_2 permits. Spot prices peaked on July 11 with 29.21 EUR but fell back to a level of approximately 22 EUR in August, remaining there until the end of 2005. Again, the beginning of an extremely cold winter in January 2006 led to a substantial increase in allowance prices up to 29.78 EUR on April 18, 2006.

Shortly after the April 2006 peak, news spread that a number of participating countries had given their industries too generous emission caps such that there was no need for them to reduce their emissions. On April 25, the Netherlands and Czech Republic announced that their emissions were 7% and 15% below the respective allocations. Prices fell dramatically within three weeks from 29.37 EUR on April 24 to 9.13 EUR on May 12. A renewed increase of spot prices to approximately 18 EUR could be observed until the end of May. Since then, a more or less continuing decrease in spot prices until the end of the trading period could be observed. By the beginning of January 2007 the prices had already decreased to approximately 5 EUR while by the end of March

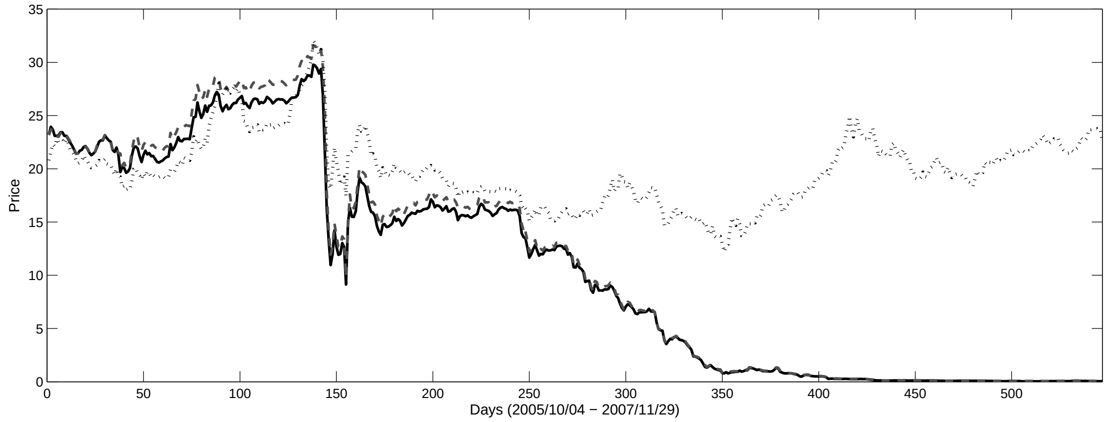

Figure 2: EUA spot price (solid) and futures prices for delivery in 2007 (dashed) and 2008 (dotted) for October 4, 2005 to November 29, 2007. Note, that the time scale uses business days, i.e. there are approximately 250 observations per year.

Table 2: Correlations between returns from spot and futures contracts for the pilot period (2006, 2007) and Kyoto commitment period (2008-2012) for market quotes from October 4, 2005 to April 24, 2006.

Delivery	Spot	2006	2007	2008	2009	2010	2011	2012
Spot	1	0.8715	0.8596	0.6259	0.6147	0.5882	0.5800	0.5733
2006		1	0.9898	0.7126	0.7034	0.6732	0.6637	0.6558
2007			1	0.7170	0.7109	0.6812	0.6716	0.6631
2008				1	0.9834	0.9462	0.9361	0.9202
2009					1	0.9608	0.9506	0.9371
2010						1	0.9939	0.9840
2011							1	0.9963
2012								1

2007 prices for the first time dropped below 1 EUR. Since then, they steadily declined and on the last trading day (December 28, 2007) a price of 0.02 EUR was observed.

To investigate the relationship between spot and futures allowance prices, we consider the time period starting from October 4, 2005, when the trading of futures contracts commenced at the EEX. Figure 2 displays pilot period spot prices as well as futures prices for contracts with delivery in November 2007 and November 2008. We find that while there is a strong similarity between spot and 2007 futures prices, there is clearly less co-movement between the spot market and futures contracts referring to the first Kyoto period. Note that during Phase I, no futures contracts for the second Kyoto commitment period were traded yet.

Tables 2 reports the correlation coefficients between daily returns of emission allowances' spot and futures prices for the period from October 4, 2005 to April 24, 2006, i.e. before the news of potential overallocation was spread, while Table 3 reports correlations for the period April

25, 2006 to August 2, 2007. Let us first consider the time period before the significant drop of spot prices in April/May 2006. The results confirm the observation of Figure 2: there is a strong correlation between the returns of spot and pilot period futures prices, yielding $\rho > 0.8$ for futures with delivery in 2006 and 2007. The correlation between spot returns and returns of futures contracts for the Kyoto period is clearly lower but still significant, yielding correlations around 0.6. The lower correlations between phase I spot and phase II futures contracts can be attributed to the fact that no banking of allowances from the pilot to the later Kyoto commitment period was allowed such that pilot period allowances cannot be used in the years 2008-2012. In general, the correlation is slightly decreasing with maturity, indicating that opinions of investors of a distant future environment are less affected by short-term price movements. Hence, we also find some evidence on the Samuelson or time-to-maturity effect. Further we observe that the returns of futures contracts for the same trading period – either the pilot or the Kyoto period – also show very high correlations. For the pilot period we get a correlation between 2007 and 2007 futures returns of approximately $\rho = 0.99$ while for the Kyoto commitment period correlations are between 0.92 and 0.99.

Correlations between contracts referring to Phase I and Phase II drop when considering data that also includes observations during and after the significant drop in April/May 2006. Note that for this analysis we only include spot prices until August 2, 2007, the first time the spot price had dropped below a value of EUR 0.10. The reason for this is that after the beginning of August 2007, there were hardly any changes in the spot price. Further, due to the EUR 0.01 tick size of trading, returns in the spot market were at least of magnitude of +10% or -10% what might bias the results of the correlation analysis. Further note that the 2006 futures contract expired on November 29, 2006 such that for this contract estimated correlations are only based on the time period April 25, 2006 - November 29, 2006. Therefore, correlations between this contract and Kyoto commitment period contracts are still fairly high. Correlations between returns of spot and futures returns within the same trading period remain still high, while the correlation between spot and Kyoto period futures returns have dropped. They are approximately 0.53 for Phase I spot and Kyoto commitment period futures contracts, and around 0.57 for the 2007 futures and Kyoto commitment futures contracts. We interpret this in a way that after the news of relatively high allocation of allowances, the price signal given by prices from contracts of the Kyoto commitment period was less relevant for the pilot trading period and vice versa. Market participants were aware that new allocation plans would be created for Phase II with allocations below those of the pilot trading period. Further, the fact that banking of allowances from the pilot to the Kyoto commitment period was prohibited, made Phase I and Phase II allowances essentially two different assets.

Figure 3 displays the term structure of emission allowance spot and futures prices with yearly maturities from November 2006 to November 2012. For each trading day in October 2005, January 2006, March 2006 and November 2006 the daily observed spot and futures prices are connected by a smoothed line using cubic interpolation. We find that the term structure of futures prices is dynamic and shows quite different behavior through time. During the initial trading period in October 2005 futures prices both for the pilot and Kyoto periods were slightly below current spot prices. While there was a quite flat term structure for the pilot period, a slightly increasing term structure of futures prices could be observed for the Kyoto commitment period. In January 2006, for the pilot period an increasing term structure can be observed while the term structure for the

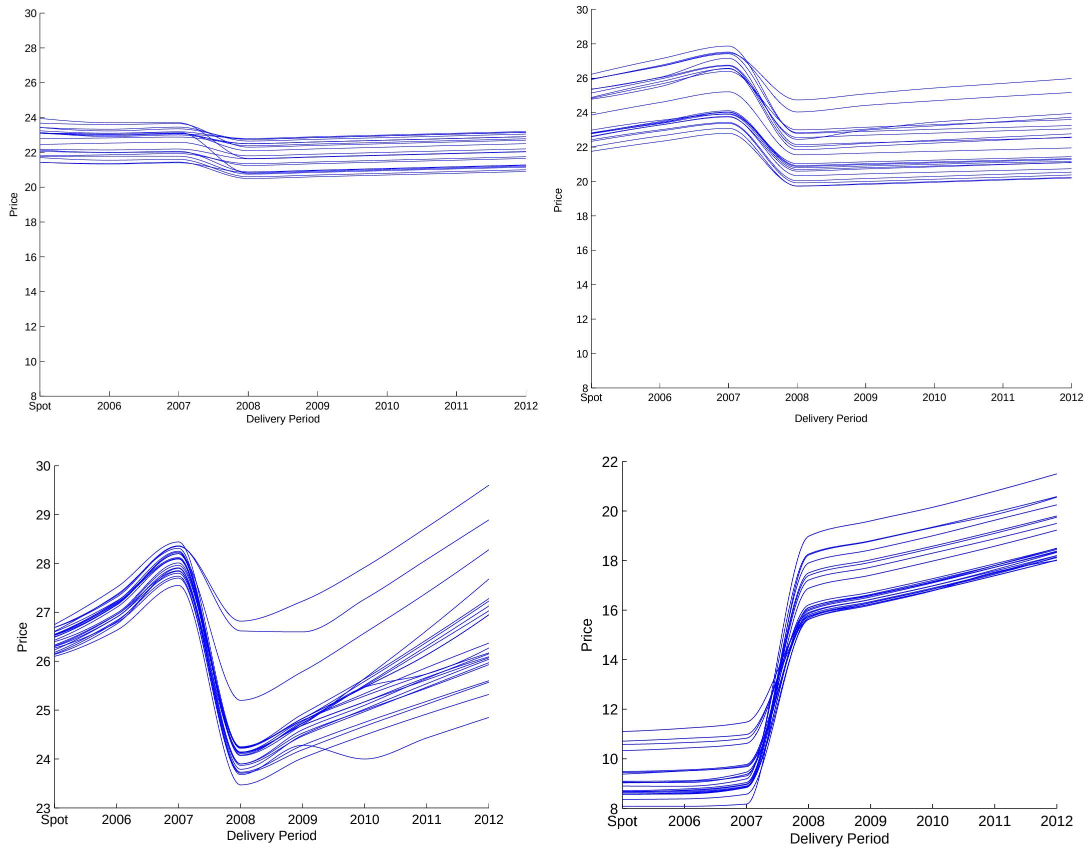

Figure 3: Term structure for spot and futures prices for each trading day of October 4 – 31, 2005 (*upper left panel*), January 1 – 31, 2006 (*upper right panel*), March 1 – 31, 2006 (*lower left panel*) and November 1 – 30, 2006 (*lower right panel*).

Kyoto period is only slightly increasing. Futures prices for the Kyoto commitment period are still below the spot price and futures prices of the pilot period. In May 2006, after the news of overallocation of emission rights in a number of European countries was published, futures prices for the Kyoto period are slightly higher than the spot and pilot period futures prices. In September 2006, a clearly increasing term structure can be observed and futures prices for the Kyoto period are significantly above the spot and pilot period futures prices. We conclude that starting from May 2006 the relationship between pilot period spot and futures and Kyoto commitment period futures prices showed significant changes. While the spot and also Phase I futures prices dropped significantly due to the news of overallocation of allowances, Kyoto period futures contracts were clearly less affected by these news. The latter can be attributed to the fact that no banking of allowances from the pilot to the later Kyoto commitment period was allowed. Further, market participants were aware that new allocation plans would be provided for the Kyoto commitment period that would most likely be below allocations for the pilot trading period.

Figure 4 displays the volatility term structure for spot and futures prices with delivery in November 2006 until November 2012. According to the Samuelson effect we would expect a declining term structure of the forward price volatility. Obviously, also the volatility term struc-

Table 3: Correlations between returns from spot and futures contracts for the pilot period (2006, 2007) and Kyoto commitment period (2008-2012) for market quotes from April 25, 2006 to August 2, 2007.

Delivery	Spot	2006	2007	2008	2009	2010	2011	2012
Spot	1	0.9761	0.9617	0.5395	0.5467	0.5447	0.5369	0.5392
2006		1	0.9979	0.8424	0.8528	0.8518	0.8500	0.8438
2007			1	0.5723	0.5758	0.5726	0.5724	0.5734
2008				1	0.9922	0.9809	0.9750	0.9646
2009					1	0.9880	0.9817	0.9720
2010						1	0.9927	0.9851
2011							1	0.9918
2012								1

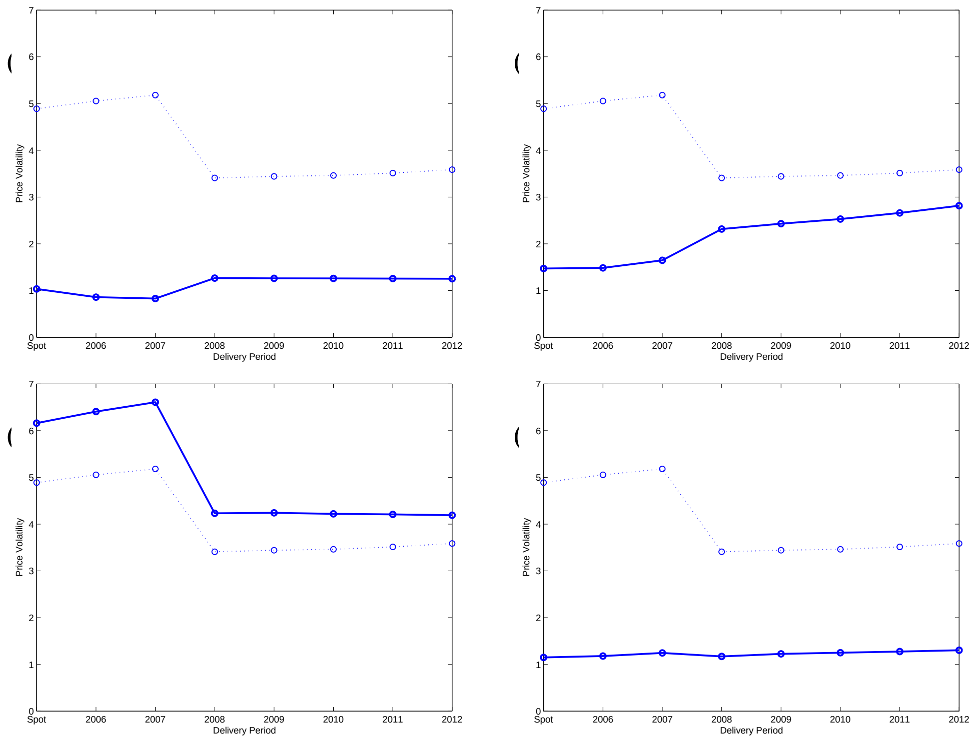

Figure 4: Volatility for spot and futures prices with delivery in 2006-2012. In all panels, the dotted line represents the volatilities for the whole period (October 4, 2005 - September 29, 2006). Bold lines represent the volatilities for the trading period October 4, 2005 - December 31, 2005 (*upper left panel*), January 2, 2006 - March 31, 2006 (*upper right panel*), April 3, 2006 - June 30, 2006 (*lower left panel*) and July 1, 2006 - September 29, 2006 (*lower right panel*).

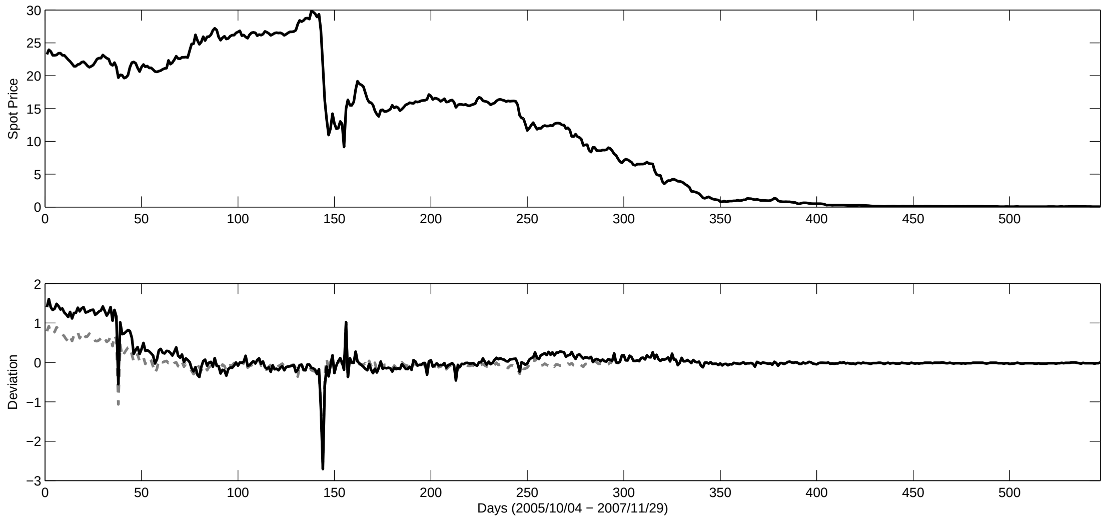

Figure 5: *Upper panel:* Spot prices (EUR/ton) from October 4, 2005 to November 29, 2007. *Lower panel:* Convenience yields (EUR/ton) for 2006 (dashed grey) and 2007 (solid) EUA futures.

ture of spot and futures prices shows strong dynamics through time. Considering the whole period from October 4, 2005 until September 29, 2006, the volatility of futures for the pilot period was higher than the spot price volatility while for the Kyoto commitment period lower volatilities in futures prices could be observed. Quite different results are obtained if subperiods are examined. For the first three months of trading (from October to December 2005), a decreasing volatility term structure for the pilot period can be observed. For the Kyoto period the volatility term structure was flat, however, futures prices showed significantly higher volatilities. From January to March 2006 there is a monotonic increasing volatility term structure in futures prices. The lowest volatility can be observed for the spot price, while the highest volatility is exhibited by the 2012 futures. A quite opposite behavior can be found for the period beginning in April until end of June. After the news of overallocation in certain countries was published, spot and pilot period futures prices showed strong reaction and exhibited extreme volatilities in comparison to the first six months of futures trading. The standard deviation on daily prices rose from approximately $\sigma = 6$ for the spot prices to approximately $\sigma = 6.5$ for the 2007 futures. Further, for the pilot period the volatility term structure is increasing. Kyoto period futures prices showed less reaction to the news and clearly less volatility. Here the term structure remains flat, the standard deviation of daily prices is approximately $\sigma = 4.2$ for all futures. For the last three months the volatility term structure is slightly increasing but quite flat. For all traded products the standard deviation of daily prices is very close to $\sigma = 1$. Overall, the results contradict other studies in the literature on the volatility of futures prices and give ambivalent results on the Samuelson effect. While we found that correlation between spot and futures prices decreases with longer maturity of the futures, separately examining the volatility of futures prices for the pilot and Kyoto periods we find a rather increasing term structure and strong dynamics through time.

We will now investigate the behavior of the convenience yield of CO_2 emission allowance futures prices for the pilot trading period. For the risk free rates we use daily European Central Bank (ECB) quotes for AAA-rated euro area central government bonds, using linear interpolation to match the yields for different time horizons until maturity of the futures contracts. Recall that under the standard cost-of-carry approach, we would expect the convenience yield to be zero such that the equation $F_{(t,T)} = e^{r(T-t)}S_t$ holds. Given equation (3), in the following we consider absolute values of the convenience yield as $\gamma_{(T-t)} = S_t e^{r(T-t)} - F_{t,T}$.

Figure 5 displays the convenience yield for the pilot period futures contract with delivery in November 2006 and November 2007. We find that the convenience yield was initially significantly different from zero for both contracts. This confirms results by other studies, e.g. Milunovich and Joyeux (2010) who report that none of the pilot period carbon futures contracts are priced according to a cost-of-carry model relationship. These authors argue that the mis-pricing could be due to a large standard error associated with the estimated parameter on the interest rate variable. We can also observe three substantial shocks or rather short-lasting spikes in the convenience yield time series, indicating a reaction of the spot/futures price relationship to market news. The most significant one is observed in April 2006 when due to the news of relatively high allocation of permits the convenience yield suddenly became negative as a consequence of the spot price dropping substantially while 2006 and 2007 futures prices still remained on a higher level for a short period of time. The closer we get to the end of the pilot trading period, the smaller becomes the convenience yield. Geting closer to the end of the pilot trading period, also the price for the 2007 futures contract approaches zero.

Overall, our findings suggest that considering the fact that banking and borrowing of allowances was allowed during the pilot period, initially there were potential arbitrage opportunities in the market for carbon permits. Since, at least for the first 6 months of trading, convenience yields were significantly different from zero and none of the futures contracts followed a cost-of-carry relationship with the spot price, market participants should have been able to apply trading strategies in order to achieve riskless profits.

Quite different results can be obtained for the relationship between Phase I spot and Kyoto commitment period futures contracts. Note, however, that due to new allocation plans for the Kyoto commitment period, the term 'convenience yield' is not really appropriate, since pilot and Kyoto period contracts refer to different trading periods and thus, also to products that are subject to different levels of scarcity. Since banking of pilot trading period allowances for usage during the Kyoto commitment period was prohibited there was no immediate benefit of holding pilot period spot contracts with regards to the Kyoto commitment period. In the following, we will refer to the difference between the spot and discounted futures price as deviation from the cost-of-carry relationship, however, we are aware that the use of this term might be somehow misleading. As indicated by Figure 6 which shows the observed deviation for 2008 and 2012 futures contracts, during the first six months of trading the yield was clearly positive with values $0 < \gamma < 10$. After the news of sufficient allocation of allowances for the pilot period, initially the price shock on allowances obviously affected Kyoto period futures contracts similar to the ones for the pilot trading period. However, the persistence of the shock on different futures contracts was of an entirely different nature: for the 2006 and 2007 futures, after a very short period with negative yields of approximately -2.5, also the futures prices for the pilot period adapted to the price change quickly and convenience yields approached zero. On the other hand, for Kyoto period

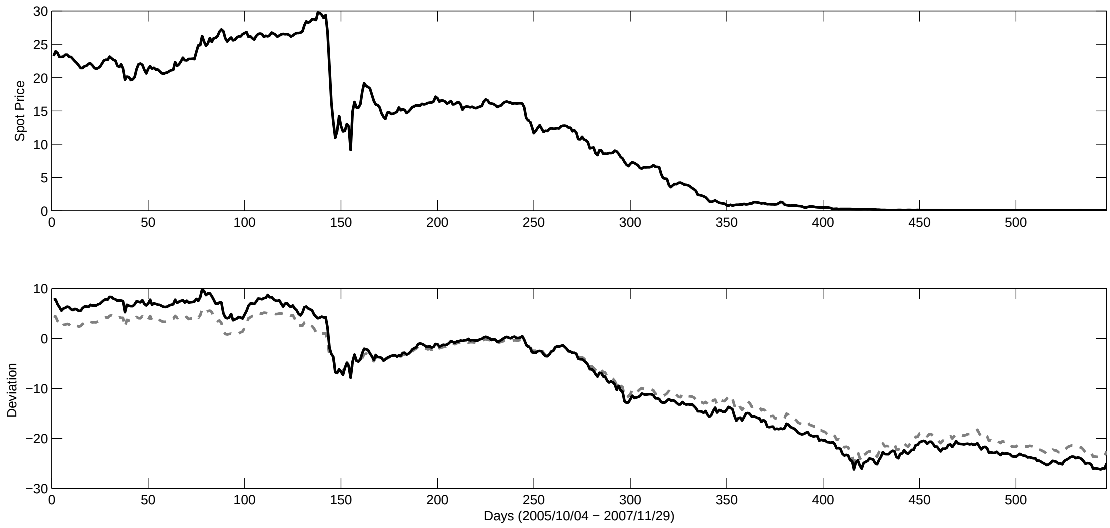

Figure 6: *Upper panel:* Spot prices (EUR/ton) from October 4, 2005 to November 29, 2007. *Lower panel:* Deviation from cost-of-carry relationship (EUR/ton) for 2008 (dashed grey) and 2012 (solid) EUA futures contracts.

futures contracts, the effect of the price shock on futures prices was not as dramatic as for the pilot period. The prohibition of banking between Phase I and Phase II and expected new NAPs for the Kyoto commitment period kept futures prices on a higher level between 12 and 25 EUR until the end of the pilot trading period in 2007. Thus, as illustrated in Figure 6, the deviation form a cost-of-carry relationship for the 2008-2012 futures contracts became significantly negative. As the price of the spot contract approaches zero, it basically equals minus one times the futures price; compare Figures 2 and 6. Overall the analysis of pilot period spot and Kyoto commitment period futures prices reveals the following relationship: while in the beginning pilot period spot prices were also considered as an indication for Kyoto commitment period allowance prices, after the news of relatively high allocation of permits, the importance of Phase I prices for Phase II futures prices dropped dramatically. Significantly higher prices for the Kyoto commitment period futures contracts indicate that market participants saw no privilege in holding the spot contract with respect to future periods. The major reason for this were the prohibition of banking between the pilot trading and Kyoto commitment period and market participants' expectations on lower allocations of allowances for the first Kyoto commitment period.

3.3. The Kyoto Commitment Period

In the following we will now consider the relationship between spot and futures contracts for the Kyoto commitment period using data from April 8, 2008 to December 31, 2012. Figure 7 provides the spot price series as well as the December 2010, 2012 and 2014 futures price for the period considered. [1] We observe that the Phase II EUA spot price (bold solid line) on April 8,

[1]Note that the 2010 futures contract expired on December 20, 2010, the 2012 futures contract on December 17. 2012, while the first price observation for the 2014 futures contract was available on December 21, 2010.

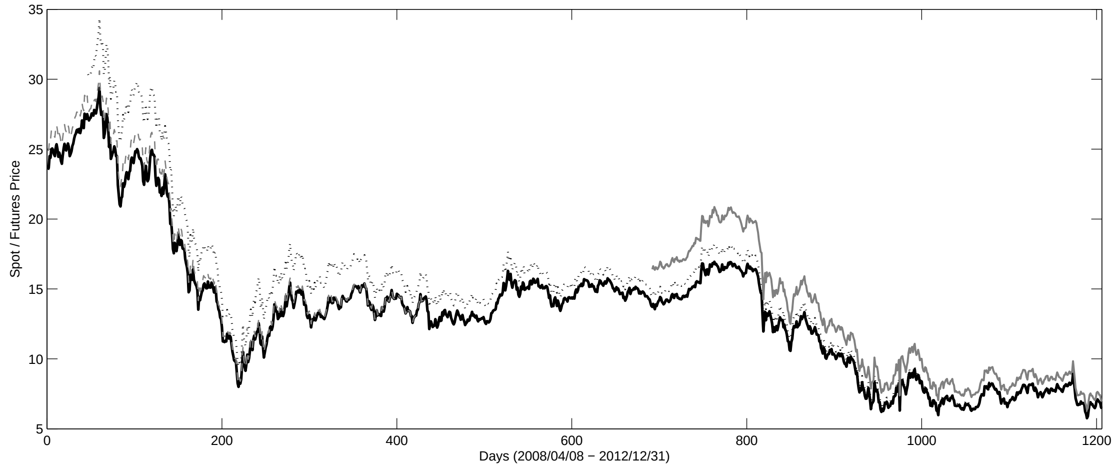

Figure 7: Spot price (solid black), December 2010 (dashed), December 2012 (dotted) and December 2014 (solid grey) futures price for the first Kyoto commitment period April 8, 2008 to December 31, 2012. The December 2010 futures contract expired on December 20, 2010, the December 2012 futures contract on December 17, 2012, while the first price observation for the 2014 futures contract was available on December 21, 2010.

2008 was EUR 23.53 and initially increased to its maximum level of EUR 29.38 on July 1, 2008. What followed was a relatively rapid decline in prices down to EUR 8.00 on February 12, 2009 which can mainly be attributed to the impacts of the financial crisis and lower expectations about economic output in the Eurozone due to the crisis. Spot prices increased again up to a level of EUR 15.45 in May 2009 and remained between in a range between EUR 13 and 16 up to June 2011. Since then, due to the European Sovereign Debt crisis, expectations about low economic output in future periods and the expectations of a relatively high allocation of allowances, prices dropped to a level of approximately EUR 6.50 in December 2012. We also observe that spot and futures prices move simultaneously during the entire period.

These co-movement of spot and futures contracts during the first Kyoto commitment period is also confirmed by looking at the correlation coefficients between spot and December 2008, 2009, ... , 2015 futures contracts in Table 4. We find that correlations between spot and futures returns are all well above 0.95 and close to one. This is also true for contracts referring to different trading period, i.e. Phase II and Phase III of the scheme. Therefore, results are quite different than what we had observed for contracts referring to the pilot and first Kyoto commitment period when inter-period banking was not allowed. Apparently, the fact that banking from Phase II to Phase III is allowed created a more similar behaviour of returns for contracts referring to either period.

Figure 8 provides a plot of the observed convenience yields for Kyoto commitment spot and December 2009, 2011 and 2012 futures contracts based on the simple cost-of-carry model described in Section 2. [2] Similar to the pilot trading period, the market started in backwardation, with positive convenience yields indicating that the spot price was above the discounted price of

[2]Note that the 2009 futures contract expired on December 14, 2009, the 2011 contract on December 19, 2011 and the 2012 contract on December 17, 2012.

Table 4: Correlations between returns from spot and futures contracts (2008-2015) for Kyoto commitment period market quotes from April 8, 2008 to December 31, 2012. Note that correlation coefficients between returns from the 2008 and 2013, 2014 and 2015 futures contracts could not be calculated because the 2008 contract expired before quotes for these contracts were available. The same is true for the correlation coefficient between 2009 and 2014, 2015 contracts and for 2010 and 2015 futures contracts.

Delivery	Spot	2008	2009	2010	2011	2012	2013	2014	2015
Spot	1.0000	0.9815	0.9915	0.9809	0.9708	0.9689	0.9897	0.9888	0.9580
2008		1.0000	0.9844	0.9732	0.9649	0.9618	-	-	-
2009			1.0000	0.9895	0.9797	0.9794	-	-	-
2010				1.0000	0.9870	0.9779	0.9784	-	-
2011					1.0000	0.9774	0.9863	0.9819	-
2012						1.0000	0.9955	0.9944	0.9626
2013							1.0000	0.9970	0.9667
2014								1.0000	0.9680
2015									1.0000

Kyoto commitment period futures contracts. In the course of time, the market situation changed from backwardation to contango for the first time in July 2008. Prices were approximately in line with the cost-of-carry relationship until end of October 2008, but afterwards the convenience yield for the contract becomes negative. During the period from March to December 2009, the convenience yield for 2011 and 2012 futures contracts was significantly smaller than zero. Overall, we find that similar to the pilot period none of the spot or futures contracts were priced according to the cost-of-carry relationship. The effect is more pronounced for futures contracts with longer maturity, like contracts maturing in December 2011 or 2012. As the contracts get closer to the expiry date, the convenience yield becomes smaller and approaches zero. The negative convenience yields for Kyoto period futures contracts from 2009 onwards indicate that market participants saw no privilege in holding the allowance now with respect to future periods. As banking and borrowing within the years of the Kyoto commitment period (i.e. 2008-2012) is allowed, one could argue that the deviation from the cost-of-carry relationship is due to a large standard error associated with the estimated parameter on the interest rate variable or to different market expectations about interest rates in forthcoming years. Recall that due to the financial crisis risk-free rates in the Eurozone started to drop significantly from a level of around 4% in September 2008 to 0.4% in September 2009 and since then have remained at a very low level.

Figure 9 displays the results for the relationship between Phase II spot and Phase III futures contracts. Note, inter-period banking between the phases is allowed such that the EU-ETS enables market participants to use Phase II permits also during Phase III. On the other hand, borrowing of permits from Phase III and using the allowances in Phase II is not allowed. Note that prices for the considered Phase III futures contracts were only available from December 16, 2009 (2013 futures), December 21, 2010 (2014 futures) and December 20, 2011 (2015 futures). Therefore, Figure 9 only provides a plot of the spot price and observed convenience yields for this time period. We find highly negative convenience yields for all Phase III futures contracts, usually in the range

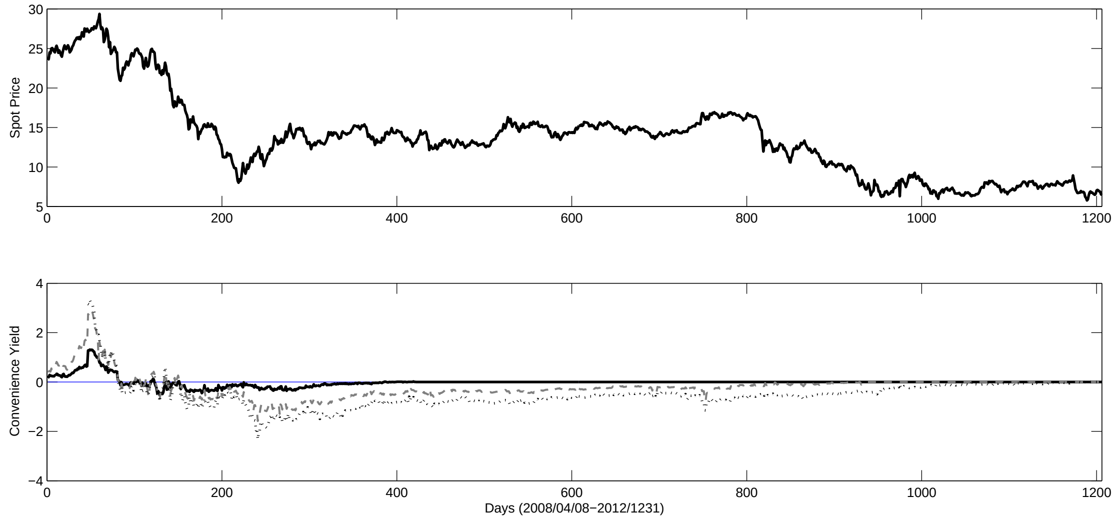

Figure 8: *Upper panel:* Spot prices (EUR/ton) from April 8, 2008 to December 31, 2012. *Lower panel:* Convenience yields (EUR/ton) for 2009 (solid), 2011 (dashed) and 2012 (dotted) EUA futures contracts. The 2009 futures contract expired on December 14, 2009, the 2011 contract on December 19, 2011 and the 2012 contract on December 17, 2012.

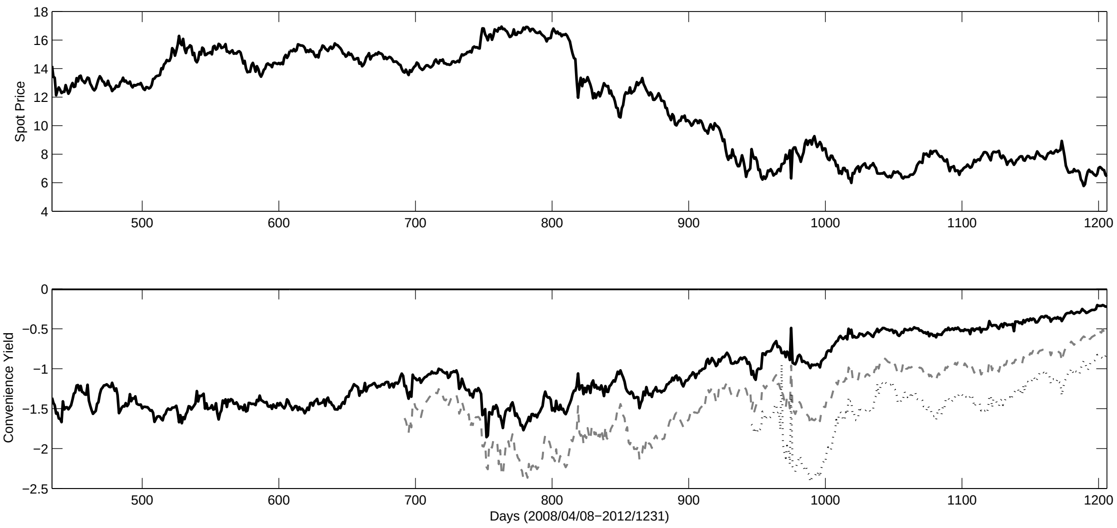

Figure 9: *Upper panel:* Spot prices (EUR/ton) from December 16, 2009 to December 31, 2012. *Lower panel:* Convenience yields (EUR/ton) for December 2013 (solid), December 2014 (dashed) and December 2015 (dotted) EUA futures contracts. Phase III futures contract prices were available from December 16, 2009 (2013 futures), December 21, 2010 (2014 futures) and December 20, 2011 (2015 futures).

between -1 and -3 for December 2009 until the end of 2011. During 2012, observed convenience yields have been reduced in magnitude, however, they remain clearly below zero for all contracts.

Note that our findings with respect to a clear deviation from the cost-of-carry relationship for Phase II are in line with earlier studies examining the relationship between EUA spot and futures contracts during the Kyoto commitment period Madaleno and Pinho (2011); Gorenflo (2013); Chang et al. (2013). However, the consistently negative sign of observed convenience yields from March 2009 onwards, at least partially contradicts results reported in these studies. While none of the earlier studies examines the relationship for the entire Phase II, Madaleno and Pinho (2011) and Chang et al. (2013) report positive convenience yields during late 2009 and 2010 for some of the futures contracts (usually contracts with maturity during Phase II, i.e. expiry in December 2010, 2011 or 2012). The key reason for the deviation in our results, may be different assumptions about the risk-free rate. While Madaleno and Pinho (2011) assume a constant interest rate for the estimation period of 4%, Chang et al. (2013) choose a constant free-risk rate equal to the average coupon rate of 3.06%, i.e. the rate for three-year government bonds issued in 2010 in the European Union. Also Gorenflo (2013) state that the interest rate is assumed to be constant over time in his analysis. Note that in our study we relax the assumption of a constant average risk-free rate and use actual daily European Central Bank (ECB) quotes for AAA-rated euro area central government bonds for different maturities. Further, to match the yields for different time horizons until maturity of the considered futures contracts we use linear interpolation between quoted interest rates. As mentioned earlier, risk-free rates in the Eurozone have dropped significantly from a level of around 4% in September 2008 to a level below 1% since late September 2009. Therefore, it is no surprise that in our analysis we obtain different results in comparison to previous studies, where a significantly higher interest rate has been applied.

Overall, there is a number of reasons that could explain the negative convenience yields and the clear deviation from the cost-of-carry relationship for Phase II. The first reason may be the extremely low risk-free rates in the Eurozone from 2009 onwards. This drop from 4% to rates near 0.5% was initially due to the financial crisis, while yields for AAA-rated government bonds have remained at such low levels ever since. Clearly, as indicated by equation (3) and (4), the risk-free rate is a key input in the cost-of-carry model and, therefore, also for deviations from this relationship and the calculation of the convenience yield. We also observe that convenience yields become more significant once risk-free rates in the Eurozone drop to the low levels we have seen since 2009. During periods of very low interest rates it may be more likely to observe negative convenience yields for risky assets. This could be a result of market expectations about rising interest rates in forthcoming periods.

Secondly, the significantly negative convenience yields for Phase II and Phase III futures contracts indicate that long positions in futures contracts are priced at a higher level than what would be suggested by the simple cost-of-carry relationship. Generally, a contango market as it is observed during Phase II would suggest currently available supply but potential medium-to-long-term shortages of a commodity. Under such a scenario, consumers might be interested in buying insurance against rising prices in the futures market. Therefore, a greater interest in long futures positions will drive prices of these contracts up to a level that is higher than what may be suggested by the cost-of-carry relationship. Therefore, observed negative convenience yields may be interpreted as consumers willingness to pay an additional premium for a hedge against rising prices or

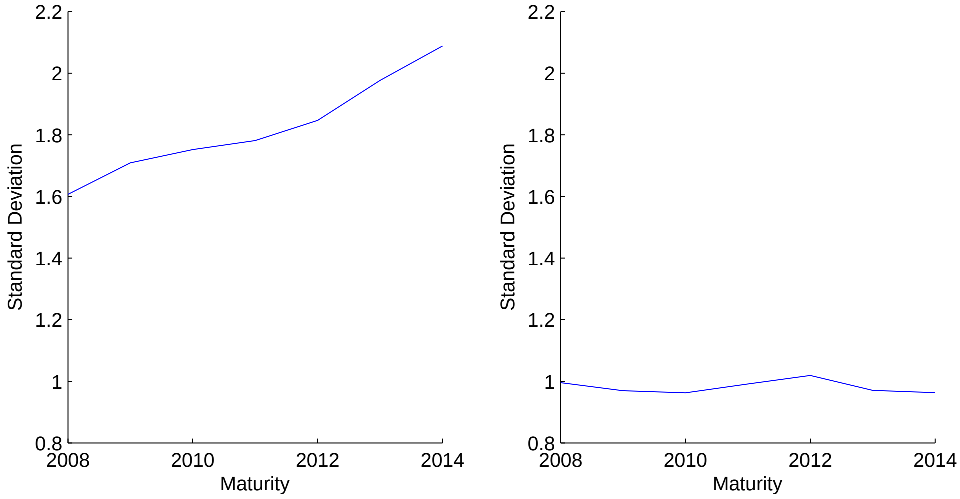

Figure 10: Volatility term structure of daily prices for the considered spot and 2009-2014 December futures contracts for the trading period July 1, 2008 – September 30, 2008 (*left panel*) and April 1 – June 30, 2009 (*right panel*).

future shortage of EUAs. Clearly, it can also be interpreted as a hedge against potential changes in regulation that may reduce the availability of permits in forthcoming years.

The last explanation refers to the possibility of banking EUAs and the surplus of allowances available during Phase II. Generally, the theory of storage would suggest a negative relationship between the convenience yield and inventory, see e.g. Pindyck (2001). The owner of a commodity, who is free to consume it until maturity, is prepared for unexpected shortages in supply or increases in demand. The convenience yield then represents this additional benefit of holding a unit of inventory, for instance, to be able to meet unexpected demand. The value of this benefit should then be negatively related to the level of inventory. One could argue that it is particularly high if inventories of a commodity are low and consumers are forced to secure a short-term supply. On the other hand, high levels of inventory will reduce the benefits and, therefore, also the convenience yield. Considering the continuously increasing level of surplus allowances during the first Kyoto commitment period [3] and the extensive use of external credits coming from two of the Kyoto Protocol mechanisms, the clean development mechanism (CDM) and joint implementation (JI), one could argue that throughout Phase II an increasingly higher level of inventory was accumulated. Therefore, the change in the market from backwardation to contango and significantly negative convenience yields for futures contracts could be a result of an increasing level of surplus allowances and banking.

Let us finally consider Figure 10 displaying the volatility term structure for spot and futures prices with delivery in December 2009 until December 2014. According to the Samuelson effect we would expect a declining term structure of the forward price volatility. Obviously, also the volatility term structure of spot and futures prices shows strong dynamics through time. Consid-

[3] See e.g. http://europeanclimatepolicy.eu/

ering the period from July 1, 2008 to September 30, 2008, the volatility of futures contracts for Phase II and Phase III was higher than the spot price volatility. Quite different results are obtained when the period from April 1 to June 30, 2009 is examined. Here, the volatility term structure is quite flat, while in other subperiods even a decreasing volatility term structure could be observed. Overall, we find a rapidly changing behavior of the volatility term structure through time that often contradicts the Samuelson effect. In fact, for many periods the volatility of futures contracts with later maturity is significantly higher than the volatility of spot prices. Overall, EUAs seem to exhibit a quite unique behavior that suggests further investigation of spot and futures CO_2 emission allowance prices in future studies.

4. Conclusions

In this paper we have conducted an empirical study on the relation between the EU CO_2 allowances' spot and futures prices during the pilot trading and the first Kyoto commitment period. In particular we have examined deviations from the cost-of-carry relationship for these contracts and the behavior of the convenience yield during Phase I and Phase II.

We find that the price behavior of emission allowances in the spot and futures market is quite different from those of other commodity markets. We observe a quite dynamic behavior of the term structure both for allowance prices and volatilities. While in general correlations between spot and futures prices decrease with time to maturity, the term structure of EUA prices shows significant changes through time. We find that both for the pilot trading and Kyoto commitment period the market has changed from initial backwardation to contango. Thus, we observe futures prices that are clearly higher than the current spot price and deviate from the standard cost-of-carry approach. Also the term structure of volatilities for spot and futures prices is subject to several changes. We find an overall increasing price volatility with maturity for both periods. This somehow contradicts the time-to-maturity or Samuelson effect that suggests a typically declining term structure in the volatility of futures prices as maturity increases.

Furthermore, the observed convenience yields in futures contracts are significantly different from zero, in particular for contracts with longer maturities. Considering the first Kyoto commitment period (2008-2012), we find that the market has changed from initial backwardation to contango with significantly negative convenience yields in futures contracts. We suggest three main reasons to explain this relatively large and persistent deviation from the cost-of-carry relationship. The first one may be the extremely low risk-free rates in the Eurozone from 2009 onwards. This drop from 4% to rates near 0.5% was initially due to the financial crisis, while yields for AAA-rated government bonds have remained at such low levels ever since. The second explanation refers to the fact that there market participants are interested in buying insurance against rising prices and, therefore, may be willing to pay an additional premium in the futures market for a hedge against changes in regulation or future shortage of EUAs that would increase permit prices. The last explanation refers to the increasing level of surplus allowances and banking during the first Kyoto commitment period. Given the negative relationship between convenience yields and the level of inventory this fact may also explain the significant negative convenience yields during Phase II. We recommend a more thorough investigation of the relationship between observed convenience yields in the CO_2 allowance futures market and the suggested factors in future work.

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