SFB 649 Discussion Paper 2006-076

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This research was supported by the Deutsche Forschungsgemeinschaft through the SFB 649 "Economic Risk".

http://sfb649.wiwi.hu-berlin.de
ISSN 1860-5664

SFB 649, Humboldt-Universität zu Berlin
Spandauer Straße 1, D-10178 Berlin

SFB 649 ECONOMIC RISK BERLIN

Convenience Yields for CO_2 Emission Allowance Futures Contracts ⋆

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Abstract

In January 2005 the EU-wide CO_2 emissions trading system (EU-ETS) has formally entered into operation. Within the new trading system, the right to emit a particular amount of CO_2 becomes a tradable commodity - called EU Allowances (EUAs) - and affected companies, traders and investors will face new strategic challenges. In this paper we investigate the nature of convenience yields for CO_2 emission allowance futures. We conduct an empirical study on price behavior, volatility term structure and correlations in different CO_2 EUA contracts. Our findings are that the market has changed from initial backwardation to contango with significant convenience yields in future contracts for the Kyoto commitment period starting in 2008. A high fraction of the yields can be explained by the price level and volatility of the spot prices. We conclude that the yields can be interpreted as market expectation on the price risk of CO_2 emissions allowance prices and the uncertainty of EU allocation plans for the Kyoto period.

Key words: *CO_2* emission trading, Commodity Markets, Spot and Futures Prices, Convenience Yields

JEL Classification: Q28, G13, C19

⋆ This research was supported by Deutsche Forschungsgemeinschaft through the SFB 649 "Economic Risk".

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1 Introduction

In January 2005 the EU-wide CO_2 emissions trading system (EU-ETS) has formally entered into operation. The EU-ETS requires a cap-and-trade program whereby the right to emit a particular amount of CO_2 becomes a tradable commodity ISI (2003). Since environmental policy has historically been a command-and-control type regulation where companies had to strictly comply with emission standards, the new trading system represents a shift in paradigms. After an initial pilot trading period from 2005-2007, in 2008 there will be a new allocation plan in each of the countries and the first Kyoto-commitment trading period will start lasting until 2012.

Since failure to submit a sufficient amount of allowances results in sanction payments per missing ton of CO_2 allowances, the new market forces companies to hold an adequate number of allowances according to their carbon dioxide output. As it is pointed out by Uhrig-Homburg and Wagner (2006), participating companies face several risks specific to the emissions trading scheme. As main sources can be named price risk of fluctuating allowance prices and volume risk, since due to unexpected fluctuations in energy demand the emitters do not know ex ante their exact demand for EUAs. However, there are also additional risks like counterparty, operational and reputational risk. The first is due to the fact that a company may enter into contracts to receive or deliver EUAs at a later date with a counterparty that could be failing to deliver in compliance with the contract. Operational risks are a consequence of possible inadequate or failed internal processes and systems like human failures or external risks the breakdown of the trading system like it happened for example in the Californian electricity exchange. Finally, reputational risk arises when a company fails compliance it may suffer severe reputational damage resulting in a decreasing number of customers. In summary, participating companies will have to develop adequate risk management strategies as well as reliable models for their demand as well as for CO_2 allowance prices to reduce the risk of facing substantial sanction payments or possible high prices for purchasing additional CO_2 allowances.

Thus, the new market not only requires regulated emitters an adequate risk management, it also provides new business development opportunities for market intermediaries and service providers like brokers or trader. While trading of EUA started with a spot market in January 2005, on October 4, 2005 also a futures market was established at the European Energy Exchange in Leipzig. Thus, market participants also have the possibility to hedge against presumed increasing or decreasing demand or prices for CO_2 allowances.

Unfortunately, the literature on the EU-ETS on price behavior, risk management or hedging with CO_2 spot or future contracts is very sparse. The majority of publications on greenhouse gas emissions assesses the US market where emission trading was already established in the early 1990s. By using industrial organization models they account for changes in parameters of technology (Rezek, 1999) and electricity demand (Schennach, 2000) and their impact on the optimal equilibrium price path. There is also a number of empirical investigations on ex-post market price analysis, among them Burtraw (1996) and Ellerman and Montero (1998).

For the European market, Maeda (2001) provides a rather theoretical analysis on banking impacts and forward pricing on the market while Uhrig-Homburg and Wagner (2006) investigate the success chances and optimal design of derivatives on emission allowances. For CO_2 market price simulation studies with respect to changes in market design parameters see e.g. Burtraw and Paul (2002), Böhringer and Lange (2005) and Schleich et al. (2006). Finally, Benz and Trück (2006) as well as Paolella and Taschini (2006) provide an econometric analysis on price behavior of allowance prices and investigate different models for the dynamics of short-term price behavior. However, non of the papers takes into account the CO_2 allowance futures market.

For other commodities like oil or agricultural products, also the relationship between spot and future prices has been investigated. 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). However, for electricity prices recent studies by Longstaff and Wang (2004) and Botterud et al. (2002) find that futures prices may also significantly exceed expected spot prices in different electricity markets in US and Europe.

The aim of this paper is twofold. To our knowledge there is no study on the relationship between emission allowance spot and futures prices or convenience yields in this relatively new market. Hence, our first goal is to provide an analysis of the market with focus on the market situation in comparison to other commodity markets. We investigate not only the relationship between the spot and futures market, but also the changing market dynamics as well as the volatility term structure of spot and futures prices. Hereby, we will also take into account the differences in price behavior between the initial pilot and the Kyoto-commitment period. By investigating these issues, one may gain substantial insight not only on the market but also on participants' evaluation of risks in the market, their reaction to price shocks and their assumptions on future emission levels or allowance allocation for the Kyoto period. Our second objective is to provide an analysis and stochastic models for the convenience yield in the CO_2 emission allowance market. Despite various theoretical discussions of the convenience yield in commodity markets, the empirical evidence regarding the theories is scant. Hence, we investigate the significance of the convenience yield in the market and its dependence on factors like the spot price level and volatility. Further, we investigate several time-series models for the stochastic behavior of the yield.

The remainder of the paper is organized as follows. Section two provides a brief introduction to the new market mechanism for CO_2 emission allowances and a classification of this new commodity. Section three reviews the relationship between spot and futures prices and explains the idea of normal backwardation or contango markets, the so-called Samuelson effect. It further illustrates the concepts of convenience yields and risk premiums for futures markets and suggest approaches for modeling observed convenience yields and risk premiums. Section four provides an empirical analysis on CO_2 spot and futures prices in the European Energy Exchange. We investigate convenience yields in the market and analyse changes in the relationship between spot and futures prices through time. We find that generally suggested models are not able to explain observed convenience yields and risk premiums in the market. Section five concludes and gives suggestions for future work on the topic.

2 The Market for Emission Allowances in the EU

Under the Kyoto Protocol the EU has committed to reducing GHG emissions by 8% compared to the 1990 level by the years 2008-2012. While allowance trading has primarily been applied in the US, the EU-ETS will result in the world's largest greenhouse gas (GHG) emissions trading system. In fact, all combustion installations exceeding 20 MW will be affected by the trading scheme including different kinds of industries like metal, cement, paper, glass etc. as well as refineries or coke ovens. In total, the EU-ETS includes some 12,000 installations, representing approximately 45% of EU CO_2 emissions. 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.

The system regulates an annual allocation of the allowances while the emission rights may either be allocated free of charge, auctioned off or sold at a fixed price. Also combination of the different allocation systems are possible. The pilot period lasts from 2005-2007, before in 2008 the first Kyoto-commitment period (2008-2012) begins. Participating companies have to indicate the amount of emitted CO_2 of the previous calendar year by March 1, and by April 30 each year, a number of allowances that is equal to the total verified emissions from that installation during the preceding calendar year has to be surrendered to the member state. An important issue in the market is the possibility to transfer surplus allowances of the previous year for use during the next year or from the 2005-2007 compliance period to the 2008-2012 compliance period.

This issue, also called *banking* is left up to the individual member states to decide and could have substantial impact on pricing of the assets. In Germany, it is not possible to bank emissions allowances from the pilot period for use in the Kyoto period. Hence, unused 2005-2007 emissions allowances become invalid after April 30, 2008. However, banking will be possible in subsequent compliance periods and be most worthwhile if increased prices for emissions allowances are expected. Borrowing is principally prohibited between 2007 and 2008, as well as between all future commitment periods. Failure to submit a sufficient amount of allowances results in sanction payments of 40 Euro per missing ton of CO_2-allowances during the pilot period and 100 Euro in the commitment periods.

Generally, a company's stock of emission allowances determines the degree of allowed plant utilization. Thus, a lack of allowances requires a company either some plant-specific or process improvements, a cut- or shutdown of the emission producing plant or the purchase of additional allowances and emission credits respectively. With the latter alternative CO_2 becomes a new member of the European commodity trading market PointCarbon (2004). There is, however, a fundamental difference between trading in CO_2 and more traditional commodities. What is actually sold is a lack or absence of the gas in question. Sellers are expected to produce fewer emissions than they are allowed to, so they may sell the unused allowances to emit to someone who emits more than her allocated amount. The emissions hence become either an asset or a liability for the obligation to deliver allowances to cover those emissions.

Benz and Trück (2006) point out the substantial differences between emission allowances and classical stocks. While the value of a stock is based on profit expectations of the firm that distributes the shares, the price for the allowances is determined directly by the expected market scarcity induced by the current demand and supply. Besides, firms by themselves are able to control market scarcity and hence the market price by their abatement decisions. It is important to note that the annual quantity of allocated emission allowances is limited and already exactly specified by the EU-Directive for all trading periods. Additionally, CO_2 emission allowances have a limited duration of validity. The value of an individual allowance expires after each commitment period. Allowing for an intertemporal transfer of emission allowances in general, the allowances lose their value once used for covering CO_2 emissions.

An appropriate approach in specifying CO_2 emission allowances is their consideration as a factor of production. The shortage of the emission allowances by reducing the emissions cap over the allocation periods classifies the assets as 'normal' factors of production. They can be 'exhausted' for the production of CO_2 and after their redemption they are removed from the market.

Accordingly, it is more successful to compare the right to emit CO_2 with other operating materials that are directly linked to a production system than with a traditional equity share. Looking for an appropriate pricing model for CO_2 emission allowances, the obvious parallels to a factor of production motivate the idea to adopt common factor pricing models (e.g. for coal, oil electricity) instead of using typical financial stock pricing models.

3 Commodity Spot and Futures Markets

3.1 Characteristics of Commodity Markets

In the previous section we specified CO_2 allowances as being very similar to a commodity or factor of production. 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. However, 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.

At time t the futures prices $F_{t,T}$ of a commodity with delivery in T can be greater, equal or less than current the spot prices of the asset S_t. Further, it can also be greater or less than the expected spot price $E_t(S_T)$ at delivery T. The futures market is said to exhibit *backwardation* when the futures price $F_{t,T}$ is less or equal the current spot price S_t, it exhibits *normal backwardation* when the futures price is less or equal the expected spot price $E_t(S_T)$ in 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 in T. Table 3.1 illustrates the four market situations.

The idea of normal backwardation was initially suggested by Keynes (1930) and Hicks (1946). The theory postulates that futures prices are usually quoted below spot prices and tend to rise over the life of a futures contract. The reason for this is that hedgers tend to hold short positions as insurance against their cash position and must pay speculators a return to hold long positions in order to offset their risk. Thus, with futures price is less than the expected spot price in T, Keynes (1930) regarded the notion of normal backwardation as equivalent to a positive risk premium since the risk is transferred to the long position in futures. Commodity markets are generally assumed

Another interesting issue is the term structure of a commodities 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 *Samuelson Effect* or as 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 distant future prices will change this month. Hence, only minor effects can be expected on futures with a long maturity. However, as the maturity date is approached, investors are clearly more sensitive to information that influence the level of the futures price at maturity.

Market Situation	Relation between (expected) spot and futures price
Backwardation	$F_{t,T} \leq S_t$
Normal Backwardation	$F_{t,T} \leq S_t e^{r(T-t)}$
Contango	$F_{t,T} > S_t$
Normal Contango	$F_{t,T} > S_t e^{r(T-t)}$

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

The literature on backwardation or contango in commodity markets shows ambiguous results. While earlier studies find some evidence to support the normal backwardation idea for several products, recent studies also observe future prices exceeding the expected future spot prices in empirical data. Bodie and Rosansky (1980) conduct an extensive study on risk and return in commodities futures for major commodities traded in the United States. Combining futures contracts the selected commodities in a portfolio they find that the mean rate of return in a period from 1950 and 1976 clearly exceeded the average risk free rate. Chang (1985) also finds evidence of normal backwardation over the period from 1951 to 1980 examining futures prices of agricultural commodities like wheat, corn and soybeans. Fama and French (1987) combine a variety of commodities like metal or agricultural products into a portfolio and investigate the risk premium in future prices. They find marginal evidence of normal backwardation, however, the risk premium in examined future prices is not significantly different from zero. In a more recent study, Pindyck (2001) investigating future markets for crude oil and heating oil finds evidence for backwardation theory in the markets. In particular, the degree of backwardation is larger during times of high volatility. Longstaff and Wang (2004) examine whether the forward risk premium paid in the PJM electricity market are significant. Their findings are positive risk premiums in futures and the negative implied excess yields. Similar results were obtained by Botterud et al. (2002) examining futures and spot prices in the Scandinavian Nordpool electricity market. Considine and Larson (2001a,b) also find backwardation with significant convenience yields in crude oil and natural gas markets, while

Milonas and Henker (2001) get similar results for international oil markets. Investigating the Samuelson effect in an empirical study on the behavior of metal prices, Fama and French (1988) found that violations of this pattern may occur when inventory is high. In particular, forward price volatilities can initially increase with contract horizon.

3.2 Relating Spot and Futures Prices

Approaches for the valuation of forward and future 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 will 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 Pindyck (2001). 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 a 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 Pindyck (2001).

Assume that we hold one unit of emission rights at time t, 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:

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

Hereby, $\psi_{(T-t)}$ 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 with delivery in T. The return of this futures contract equals then $F_{t,T} - S_T$. Note that there is no risk involved in the transactions and the total return is non-stochastic and should equal the risk-free rate for the period $T - t$ times the current spot price of the emission right:

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

Solving for $\psi_{(T-t)}$ we get with the following equation for the convenience yield:

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

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: as 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.

Note that in markets where the commodity is non-storable like e.g. electricity, the no-arbitrage fails. If the commodity is perishable, there is no possibility of obtaining a risk-free position by buying the commodity in the spot market and selling in the futures market. Still the problem can be circumvented: Eydeland and Geman (1998) valuing electricity options use the forward contracts as hedging instrument while Lucia and Schwartz (2002) solve the problem by making an ad-hoc assumption about the market price of risk whose governing the change from the objective to the pricing measure.

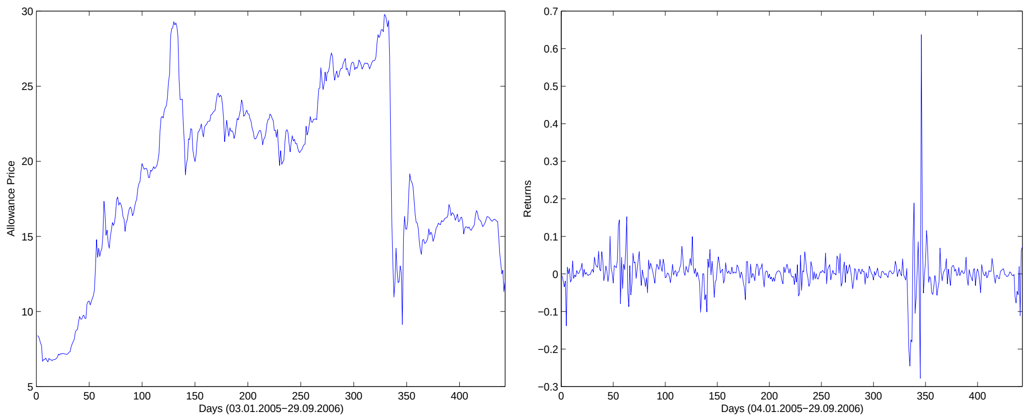
3.3 Modeling the Convenience Yields

In the following we will suggest different model specifications for determination of the convenience yield. Following Pindyck (2001) it seems reasonable to assume that the convenience yield depends on the current price level, the price volatility and the level of storage. A similar approach is suggested by Nikolaos and Henker (2001) to model convenience yields in the US oil market, while Wei and Zhu (2006) use a mixture of explanatory and time series variables to model the stochastic behavior of convenience yields.

For the EU-ETS, increasing spot prices may reflect an imbalance between supply and demand indicating that the market participants assume that the number of allocated emission allowances for the current period is insufficient. However, the effects of current spot prices for the Kyoto trading period are difficult to predict. In our empirical analysis, we will use the following model based on allowance spot price level and volatility to explain the convenience yield:

$$\psi_t = \beta_0 + \beta_1 S_t + \beta_2 \sigma^2_{S_t} + \varepsilon_t \tag{4}$$

Facing an increase in spot prices, on the one hand, market participants may go long in the futures market to hedge against further increasing prices in forthcoming periods. On the other hand, there will be forthcoming new allocation plans for the Kyoto period such that futures prices will not be affected by increasing spot prices. In this case, the convenience yields - as the difference between the expected spot price and the futures price - might also increase with the spot price level. In terms of the effect of the volatility on the convenience yields, for other commodities it is generally assumed that a high volatility in the spot market may lead to an increase in the demand for storage due to the greater need to buffer fluctuations in production Pindyck (2001). Since currently there is no information on the storage of emission allowances available, the variable was omitted from our model. However, note that the amount of storage may also affect the convenience yields. The lower the storage level is, the higher the value will be for the marginal storage.



(a) Spot Prices (b) Returns

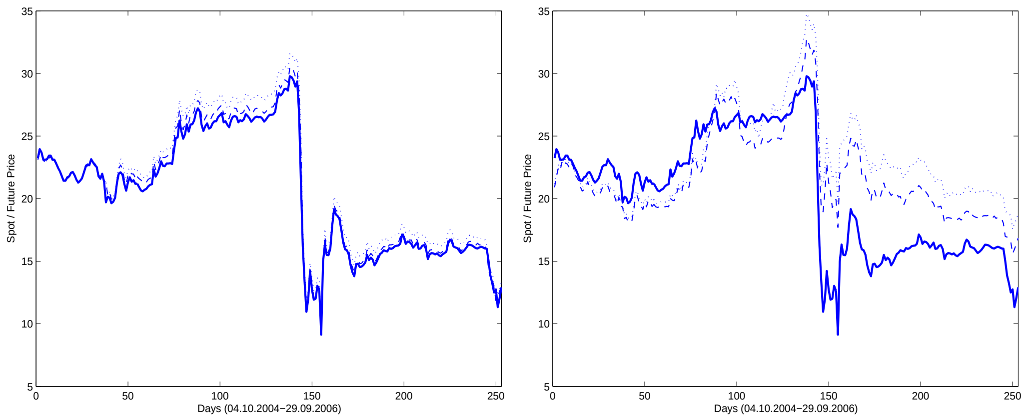
Fig. 1. EEX emission allowance spot prices (*left panel*) and returns (*right panel*) for Oct 4, 2005 - September 29, 2006

4 Empirical Results

4.1 The Data

For our analysis we use all spot and futures quotes available on the European Energy Exchange (EEX) in Leipzig during the time period from October 4, 2005 to September 29, 2006. Hence, the time period comprises approximately the first year of futures trading at EEX. Spot contracts for EU emission allowances have a contract volume of 1 ton CO_2 and are traded in Euro up to two decimal points. The object of a European Carbon Future contract is the delivery of EU emission allowances for the first period of three years beginning on January 1, 2005 or for the second period of five years beginning on January

1, 2008. Hereby, the contract volume amounts to 1,000 t CO_2 while maturity occurs on the last day of trading of a futures contract, namely the penultimate exchange trading day in the month of November 2006 and 2007 for the pilot period and November 2008 to 2012 for the Kyoto commitment period. For every futures contract a settlement price in accordance with the current 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 in cash or debited with him in cash. Delivery of the EU emission allowances will be carried out two settlement days after maturity of a futures contract, i.e. on the first settlement day in December of the corresponding year.



(a) Pilot Period

(b) Kyoto Period

Fig. 2. EEX emission allowance spot prices (bold), future prices with delivery in 2006 (dashed) and 2007 (dotted) (*left panel*), future prices with delivery in 2009 (dashed) and 2012 (dotted) (*right panel*) for Oct 4, 2005 - September 29, 2006.

While spot trading started already in January 2005, when the EU-wide CO_2 emissions trading system entered into operation, future contracts were traded only since October 2005. Figure 1 displays spot prices and returns of CO_2 emission allowance prices for the complete spot price trading period from January 3, 2005 till September 29, 2006. At the commencement of the trading period, prices initially fell due to a quite mild climate and high supply of wind energy from Scandinavia and North Germany. However, at the end of January an extreme cold snap and constant high UK gas and oil prices, compared to relatively low coal prices, led to a drastically price increase within the next months. This effect was boosted by an extremely dry summer in the southwest of Europe. The consequence of the high temperature and absence rainfall was to prevent full utilization of hydraulic plants, especially in Spain. Additionally, the lack of cooling water for nuclear power plants led to a higher power plant utilization and therefore increased the demand for $\mathrm{CO_2}$ permits. Prices peaked on July 11 with 29.21 Euro but fell back to a level of approximately 22 Euro 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

Delivery	Spot	2006	2007	2008	2009	2010	2011	2012
Spot	1	0.998	0.995	0.805	0.769	0.728	0.683	0.637
2006		1	0.998	0.814	0.779	0.739	0.696	0.650
2007			1	0.830	0.799	0.762	0.722	0.679
2008				1	0.997	0.988	0.973	0.954
2009					1	0.997	0.988	0.973
2010						1	0.997	0.988
2011							1	0.997

Table 2
Correlations between spot and futures prices for the pilot period (2006, 2007) and Kyoto commitment period (2008-2012).

allowance prices. While temperature remained cold also in April 2006, the so far highest price could be observed on April 18 with 29.78 Euro. Shortly after this news spread that many countries participating in the EU-ETS had given their industries so generous emission caps that there were no need for them to reduce emissions. Prices fell dramatically within three weeks from 29.37 Euro on April 24 to 9.13 Euro on May 12. Until the end of May a renewed increase of spot prices to approximately 18 Euro could be observed until the end of May. In June prices fell to approximately 14 Euro in June and remained between 14 and 17 Euro until mid September. Finally, in September during the last two weeks of the considered period prices fell approximately 12 Euro. Obviously, allowance returns show phases of different volatility behavior, in particular during summer 2005 and April/May extreme returns could be observed.

4.2 Relationship between Spot and Futures Prices

To investigate the relationship between spot and future allowance prices, we will consider the time period starting from October 4, 2005 until September 29, 2006, when both spot and futures were traded at EEX. Figure 2 in the left panel displays spot and emission allowance future prices for delivery in 2006 and 2007 while the right panel shows the futures prices for delivery in 2009 and 2012 for the considered time period. We find that while there is a strong similarity between spot and futures prices with delivery in 2006, futures prices for the Kyoto period show clearly less movement with the spot market.

Table 2 reports the correlation coefficients between daily spot and future prices. The results confirm the observation of figure 2: there is a very strong correlation between spot and pilot period futures prices, yielding $\rho > 0.99$ for futures with delivery in 2006 and 2007. The correlation between spot and

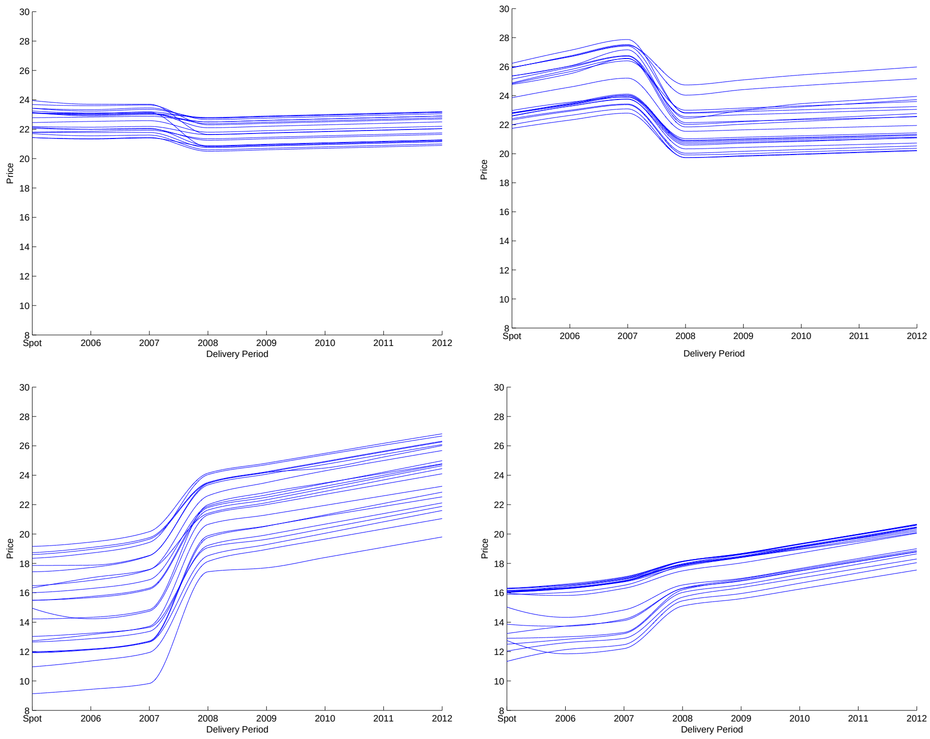


Fig. 3. Term structure for spot and futures prices for each day of Oct 4 - 31, 2005 (*upper left panel*), January 1 - 31, 2006 (*upper right panel*), May 1 - 31, 2006 (*lower left panel*) and September 1 - 29, 2006 (*lower right panel*).

futures prices for the Kyoto period is clearly lower but still significant yielding correlation between 0.637 and 0.805. The correlation is decreasing with maturity indicating that opinions of investors of a distant future environment are less affected by shoer-term price movements. Hence, we find some evidence on the Samuelson or time-to-maturity effect. Further we observe that futures prices for same trading period - either the pilot or the Kyoto period - also show very strong correlations. For the pilot period we get $\rho = 0.991$ while for the Kyoto commitment period correlations are between 0.974 and 0.999. We conclude that futures for either the pilot or Kyoto period show a very similar price behavior.

Figure 3 displays the term structure of emission allowance spot futures prices with yearly maturities from November 2006 to November 2012. For each trading day in October 2005, January 2006, May 2006 and September 2006 the observed spot and futures prices are connected by a smoothed line, yielding between 20 (October 2005) and 23 lines (May 2006) in each of the subfigures. Lines are smoothed using the Matlab 'smoothline' routine. 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 period were slightly below current spot prices. While there was a quite flat term structure for the pilot period, a slightly

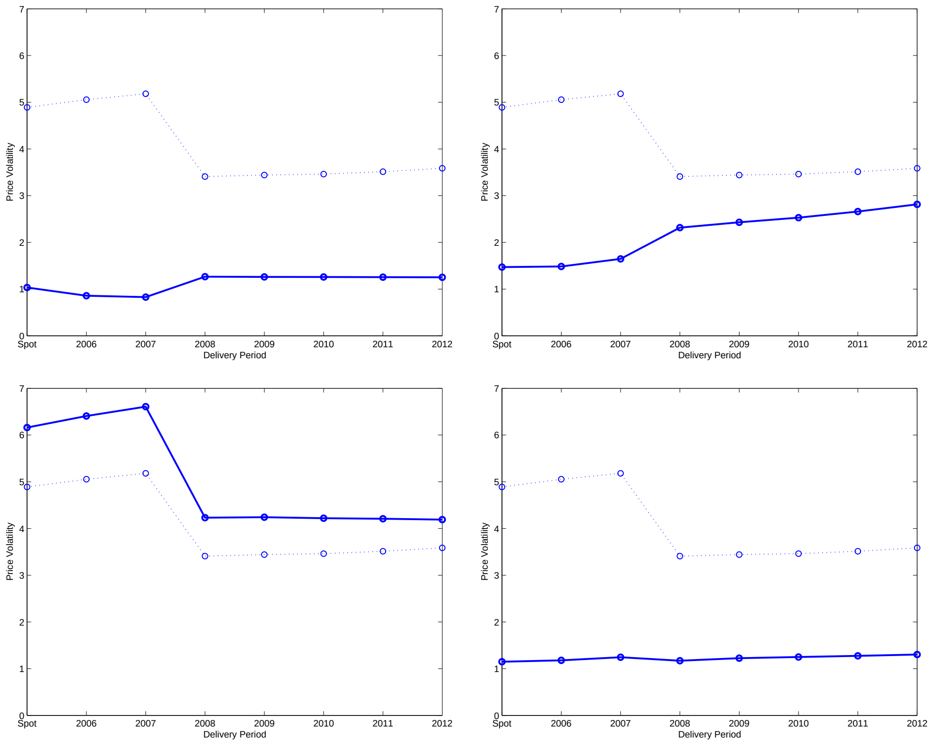


Fig. 4. Volatility for spot and futures prices with delivery in 2006-2012. Bold lines represent the volatilities for the initial trading period October 4, 2005 - December 31, 2005 (*upper left panel:*), the period January 2, 2006 - March 31, 2006 (*upper right panel:*), the period April 3, 2006 - June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

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 Kyoto period is only slightly increasing. Futures prices for the 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 spread, futures prices for the Kyoto period are clearly higher than the spot and period 1 futures prices. A similar relationship between spot and futures prices can be found for the last month of the examined period. In September 2006, an increasing term structure can be observed and futures prices for the Kyoto period are still above the spot price and period period future prices. We conclude that since May 2006 the market indicates contango, since a increasing futures price for all maturity periods can be observed. This contradicts various results on other commodities where markets were in backwardation, e.g. Pindyck (2001), Considine and Larson (2001a,b) or Milonas and Henker (2001).

Figure 4 displays the volatility for spot and futures prices with delivery in November 2006 until November 2012, respectively. 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. 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 future prices could be observed. Overall, for both periods the term structure was increasing. Quite different results are obtained, if subperiods are examined. For the first three months of the trading period 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 reaches from approximately $\sigma = 6$ for the spot prices to approximately $\sigma = 6.5$ for the 2007 future. 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 is 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 gives ambivalent results on the Samuelson effect. While we found that correlation between spot and futures prices decreases with longer maturity of the futures, seperately examining the volatility of futures prices for the pilot and Kyoto period we find a rather increasing term structure and strong dynamics through time.

4.3 Convenience Yields

In this section we will investigate the behavior of convenience yields of CO_2 emission allowance futures prices. Due to the results of the previous section, we will expect the market to behave differently to other commodity markets. For example, starting from mid April 2006, futures prices for the Kyoto period were significantly higher than the spot, so we expect to observe a negative convenience yield for this period. The necessary risk free rates were obtained

Maturity	Mean	Std.	p-value	Min	Max	Skew	Kurt
2006	0.0318	0.3619	0.1636	-2.5335	0.9756	-0.7199	13.1000
2007	0.1779	0.5594	0.0000	-2.7060	1.6088	0.5900	5.7801
2008	0.9776	3.2962	0.0000	-7.3871	5.9008	-0.4433	2.0199
2009	1.3548	3.5936	0.0000	-7.2254	6.7947	-0.4294	1.9130
2010	1.7978	3.9183	0.0000	-7.4642	7.7495	-0.4155	1.8272
2011	2.2969	4.2550	0.0000	-7.6728	8.7584	-0.4015	1.7568
2012	2.8619	4.6102	0.0000	-7.8370	9.8560	-0.3885	1.6959

Table 3
Descriptive Statistics and p-value for t-test with $H_0 : \bar{\psi} = 0$.

using 3-month and 6-month Euribor rates for short-term periods and swap based zero coupon yields for the long-term interest rates up to 2012. To match the yields for different time horizons we used linear interpolation.

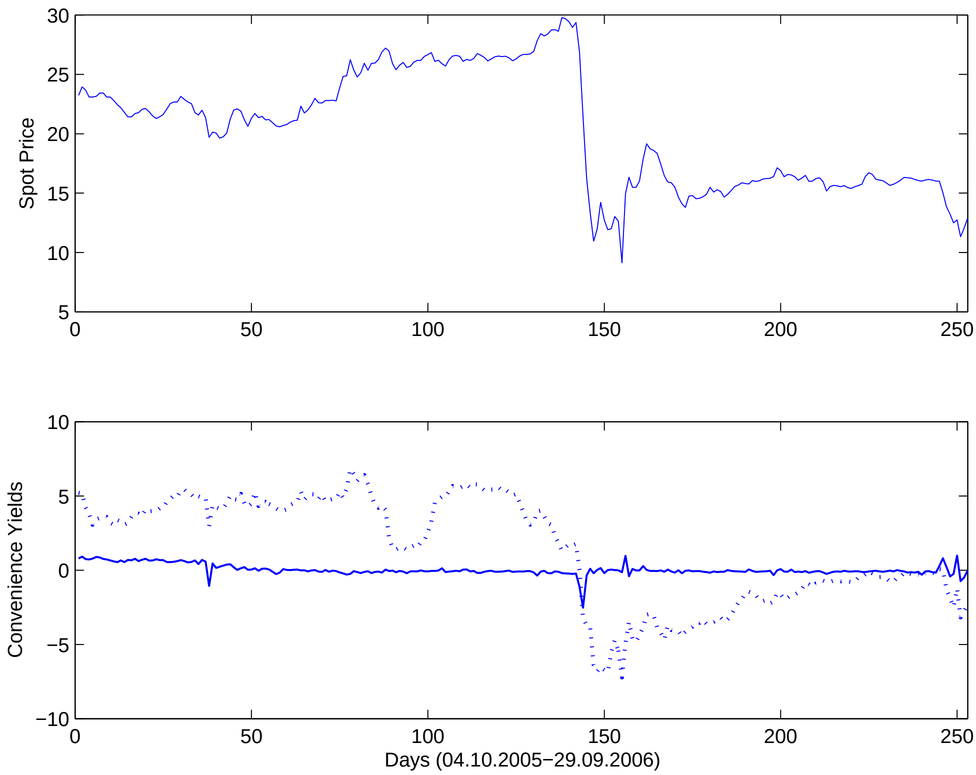


Fig. 5. *Top panel:* Spot price of emission allowance from October 3, 2005 to September 29, 2006. *Bottom panel:* Convenience Yields in Futures Prices with delivery in 2006 (bold) and 2009 (dotted).

Figure 4.3 displays the convenience yield for a pilot period futures contract with delivery in November 2006 and a Kyoto period futures contract with delivery in November 2009. From a first glance we find that the time series for the convenience yields for the pilot and Kyoto period futures behave quite differently. Table 4.3 shows the descriptive statistics including a the p-values of a t-test for significance for the convenience yields of the 2006-2012 futures. We find that for the pilot period the convenience yields are less significant but exhibit high kurtosis and skewness. With increasing time to maturity declining kurtosis and less skewness can be observed, while the yields for the Kyoto period are significantly different from zero. In the first three months, the yield is positive with values $3 \leq \psi \leq 6$, while in January and February 2006 higher higher volatility can be observed with ψ ranging from a minimum of 1.375 up to 6.795 on January 20. After the news of overallocation of allowances for the pilot period was published, the price shock on allowances also had an effect on observed convenience yields. However, also the persistence of the shock on convenience yields was of a completely different nature. While for the 2006 future, after a very short period with negative yields of -2.550 also the future prices for the pilot period adopted to the price change quickly and observed convenience yields were close to zero. A quite different behavior could be observed for the Kyoto period futures and convenience yields. The effect of the price shock on futures prices were not as dramatic as for the pilot period. This becomes obvious by examining the left panel in figure 2, where prices for the 2009 and 2012 futures remained on a significantly higher level than the spot price and in the lower left panel of figure 4 indicating the clearly lower volatility of Kyoto period futures prices during the April to June 2006 period. As a consequence convenience yields for the 2009 future contract became significantly negative with the overall minimum of -7.225 on May 12.

The results are confirmed by figure 6 displaying the similar behavior of convenience yields for the pilot period, namely the 2006 and 2007 future as well as for the Kyoto period, namely the yields in futures prices with delivery in November 2009 and 2012. We find that there is a strong similarity in the time series for convenience yields in either period, while completely different long-term reactions to the price shock can be observed. Only considering the Kyoto commitment period, the CO_2 allowance market has changed from initial backwardation to contango after the price shock in April and May 2006. The persistence of high negative convenience yields in Kyoto period futures prices may be interpreted as the market participants expectations on lower allocations for the commitment trading period.

4.4 Modeling Convenience Yields

In this section we will use the models described in section 3.3 to explain the behavior of the convenience yields. For each of the convenience yield time series, we estimated a model according to equation (4) where the convenience

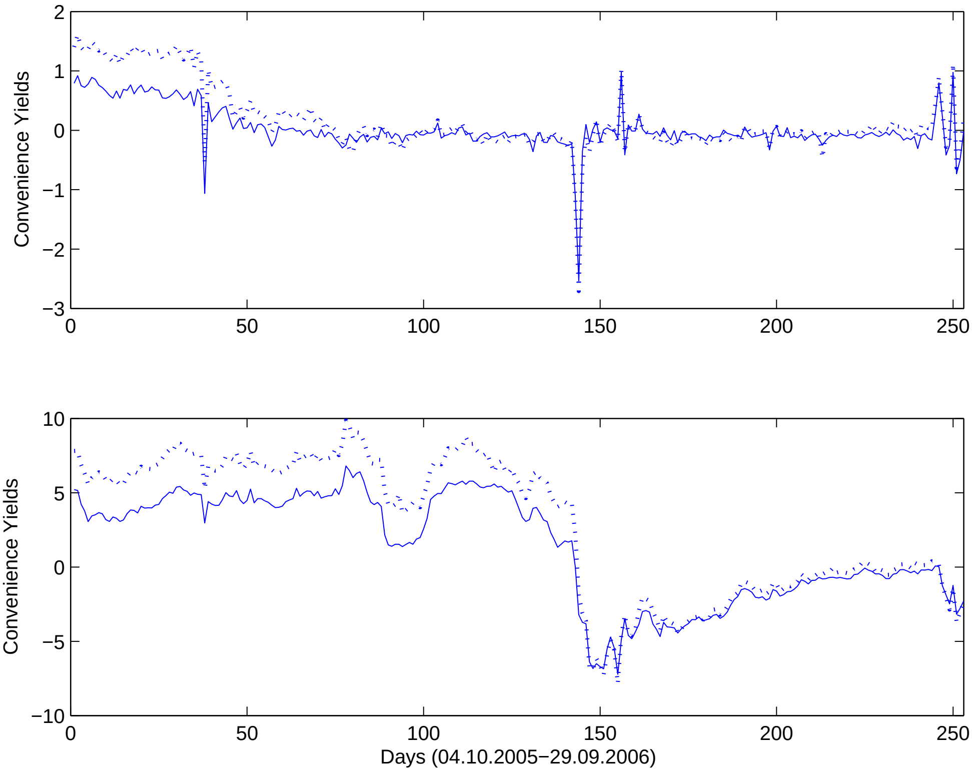


Fig. 6. *Top panel:* Convenience Yields in Futures Prices with delivery in November 2006 and 2007 (dotted). *Bottom panel:* Convenience Yields in Futures Prices with delivery in November 2009 and 2012 (dotted).

yield is regressed on the current spot price level and its volatility. Hereby, different approaches could be used to measure the volatility of the spot price in period t. Alternatives include the squared return in period t, moving averages, an exponential smoothing model, estimates from a least squares linear regresion model, autoregressive or GARCH models to name just a number of possibilities. We decided to consider only two of them, namely we consider the actual volatility of period t measured by:

$$\sigma_t^2 = r_t^2 \tag{5}$$

and a moving average of length m:

$$\sigma_t^2 = \frac{1}{m} \sum_{j=0}^{m-1} \sigma_{t-j}^2, \quad \text{where } \sigma_i^2 = r_i^2 \tag{6}$$

For m, different periods of length equal to one week $m = 5$, one month $m = 20$ and three months $m = 60$ are considered. Further, we also tested the square root of the variance moving as estimator for the volatility. Surprisingly, for all three specifications, using the standard deviation instead the variance gave better results. In terms of explanatory power the best results were obtained using a moving average length $m = 20$ equal to one month. The results for the models using the current observed volatility and the 20-day moving average are reported in table 4 and 5. Obviously, a simple two-factor model provides a quite high explanatory power for the observed convenience yields for the Kyoto commitment period. Unfortunately, the model is not able to explain convenience yields for the pilot period adequately. Investigating the coefficients of the significant model for the Kyoto period, we find that also all coefficients are significant at least at the 5% level, while for the model using a moving average for the volatility both spot price and the volatility were significant even at the 1% level. We observe a significant positive relationship between the spot price level and convenience yields while the spot price volatility exhibits negative correlation with convenience yields. Thus, especially during the dramatic decrease in allowance spot prices in April and May 2006 we observe substantial negative yields. The effect was boosted by the high volatility in spot prices at that time. Hence, high volatility and decreasing spot prices generally correspond to negative convenience yields and a contango market for the Kyoto period as it could be observed for example in May 2006 after the price shock. Overall, after the shock due to the spot prices remaining at a comparably low level the market still exhibits negative convenience yields.

The influence of the spot price level on convenience yields may be interpreted the following way: the spot price level is correlated with a positive sign to the convenience yield. However, the knowledge of forthcoming new allocation plans decreased the effect of increasing or decreasing spot prices on futures prices. As a consequence futures prices remained more stable. Hence, convenience yields - as the difference between the expected spot price and the futures price - increased or decreased with the spot price level. Especially when a price shocks like in April and May 2006 happen, convenience yields become significantly negative.

Overall, we find that the convenience yields for the Kyoto period can be explained to a high degree by the spot price level and volatility, while the yields for the pilot period seem to be rather stochastic. Recall that the convenience yield obtained from holding a commodity can be regarded as being similar to the dividend obtained from holding a company's stock representing the privilege of holding a unit of inventory. Thus, the significantly negative convenience yields for the Kyoto period indicate that market participants see no privilege in holding the allowance now with respect to future periods. This is due to the expectations on lower allocations for the Kyoto commitment period.

In a last step we try to explain the dynamics of the pilot period convenience yields by a stochastic model. Hereby, we examined the daily changes in convenience yields for the considered time period. Figure 7 shows a histogram

Pilot Period						
Year	β_0	β_1	β_2	R^2	F_{model}	p_{model}
2006	-0.0916	0.0058	1.3513	0.0138	1.7508	0.1757
	0.0986	0.0047	0.8626			
2007	-0.0990	0.0134	0.8286	0.0141	1.7818	0.1705
	0.1524	0.0072	1.3333			
Kyoto Period						
Year	β_0	β_1	β_2	R^2	F_{model}	p_{model}
2008	-9.7492**	0.5285**	-12.3058**	0.6460	228.1527	0.0000
	0.5379	0.0256	4.7072			
2009	-10.5147**	0.5846**	-12.5154*	0.6617	244.4960	0.0000
	0.5733	0.0272	5.0171			
2010	-11.3896**	0.6493**	-12.6376*	0.6831	269.4097	0.0000
	0.6051	0.0288	5.2949			
2011	-12.2268**	0.7148**	-12.6850*	0.6991	290.4448	0.0000
	0.6402	0.0304	5.6024			
2012	-13.0549**	0.7832**	-12.8949*	0.7127	310.1244	0.0000
	0.6778	0.0322	5.9312			

Table 4
Coefficients and standard errors for the estimated regression models, using $\sigma_t^2 = r_t^2$ as estimator for the volatility of spot price returns. *, ** indicate significance at 5% and 1% level, respectively.

and the time-series of daily changes in the convenience yields for the future with maturity in 2006. The figure indicates that there are some quite extreme daily changes while the time series seems to exhibit non-constant variance. Testing with the Lagrange multiplier ARCH test statistics (Engle, 1982) the heteroskedastic effects are highly significant. Hence, to capture the heteroscedasticity in the daily yield changes we calibrate a GARCH(p, q) model where for the mean as well as the variance equation different specifications were tested. For both the 2006 and 2007 convenience yields we find that a MA(1) for the mean and a GARCH(1,1) for the variance equation seem to be most appropriate, parameter estimates for higher orders of p or q were not significant. Thus, we obtain the simple setup of an MA(1)-GARCH(1,1) model and the following variance equation:

$$\varepsilon_t = u_t \sigma_t, \quad \text{with} \quad \sigma_t^2 = k + \alpha \varepsilon_{t-1}^2 + \beta \sigma_{t-1}^2, \tag{7}$$

Pilot Period						
Year	β_0	β_1	β_2	R^2	F_{model}	p_{model}
2006	-0.0486	0.0041	-1.0528	0.0047	0.5962	0.5517
	0.1076	0.0050	2.7830			
2007	0.0379	0.0081	-7.4480	0.0244	3.1280	0.0455
	0.1647	0.0076	4.2591			
Kyoto Period						
Year	β_0	β_1	β_2	R^2	F_{model}	p_{model}
2008	-8.0252**	0.4624**	-120.5297**	0.7260	331.1703	0.0000
	0.5143	0.0238	13.3009			
2009	-8.7110**	0.5154**	-125.6788**	0.7353	347.1453	0.0000
	0.5511	0.0255	14.2535			
2010	-9.5332**	0.5781**	-129.0631**	0.7486	372.1311	0.0000
	0.5856	0.0271	15.1459			
2011	-10.3081**	0.6412**	-132.9555**	0.7584	392.3348	0.0000
	0.6234	0.0288	16.1231			
2012	-11.0856**	0.7077**	-136.3100**	0.7659	408.9135	0.0000
	0.6648	0.0307	17.1954			

Table 5
Coefficients and standard errors for the estimated regression models, using $\sigma^t = \sqrt{\frac{1}{m}\sum_{j=0}^{19} r_{t-j}^2}$ as estimator for the volatility of spot price returns. *, ** indicate significance at 5% and 1% level, respectively.

where u_t is i.i.d. with zero mean and finite variance.

Table 6 shows the parameter estimates of the model for the variance equation. The estimated parameters are highly significant and figure 8 showing a normal probability plot of the standardized residuals after fitting the MA(1)-GARCH(1,1) model indicates that the model fits the data quite well. However, some of the extreme changes, especially those taking place during the price shock period in April and May 2005 cannot be explained by the model. For future work a model also including a jump component for the yields could be implemented.

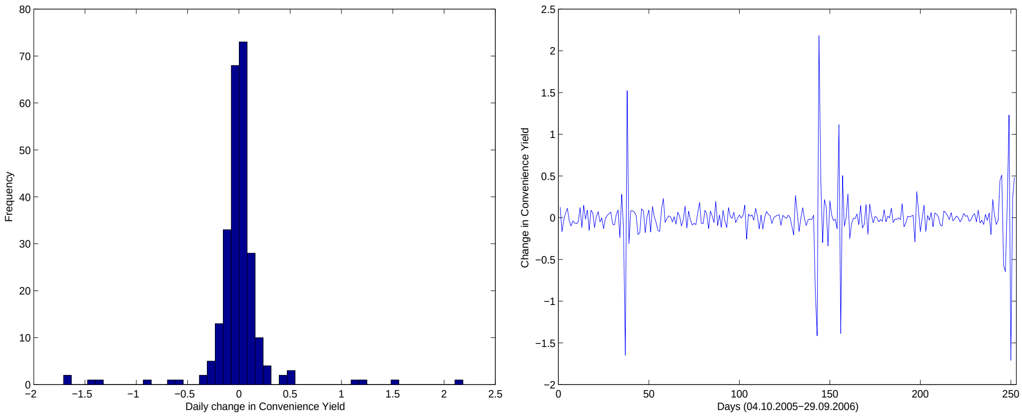


Fig. 7. Histogram (*left panel*) and time-series (*right panel*) of convenience yields' daily changes for 2006 future.

Maturity 2006			
	Coefficient	Std. Error	t-Statistic
k	0.0050	0.0004	11.0306
GARCH(1)	0.6429	0.02277	28.2372
ARCH(1)	0.3571	0.06375	5.6014
Maturity 2007			
	Coefficient	Std. Error	t-Statistic
K	0.0089	0.0011	7.7342
GARCH(1)	0.2947	0.0508	5.8023
ARCH(1)	0.7053	0.0903	7.8069

Table 6
Parameter estimates of the GARCH(1,1) model for the daily changes in convenience yields of the pilot period.

5 Conclusion

In January 2005 the EU-wide CO_2 emissions trading system (EU-ETS) has formally entered into operation. Before the trading system, regulation of greenhouse gas emissions were of command-and-control type where companies had to strictly comply with emission standards. Hence, the new trading system represents a shift in paradigms of environmental policy in the European Union. Within the new trading system, the right to emit a particular amount of CO_2 becomes a tradable commodity and affected companies, traders and investors

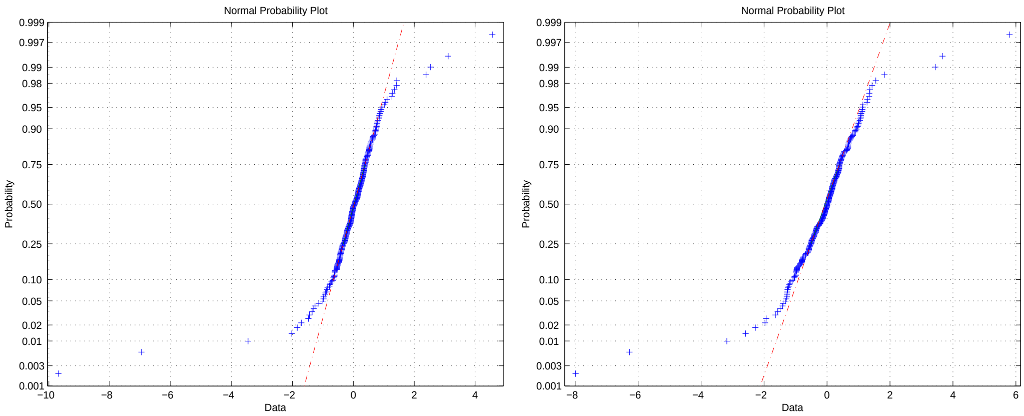


Fig. 8. Normal probability plot of the standardized residuals after fit of a MA(1)-GARCH(1,1) model to daily changes in convenience yields' with maturity in 2006 (*left panel*) and 2007 (*right panel*).

will face new strategic challenges. We conduct an empirical study on the relation between allowances' spot and futures prices, in particular we examine the volatility term structure and correlations in CO_2 of spot and futures contracts and convenience yields in the market. Our findings are a quite dynamic behavior of the term structure for allowance prices and volatilities. While in general correlations between spot and futures prices decrease with time to maturity, the term structure of prices shows significant changes through time. We observe that the market has changed from initial backwardation to contango where futures prices especially for the Kyoto commitment period are clearly higher than the current spot prices. Also the term structure of volatilities for spot and futures prices is subject to several changes. Overall, seperating the pilot period from the Kyoto period, we find an overall increasing price volatility with maturity for both periods. This contradicts the time-to-maturity or Samuelson effect that suggests a typically declining term structure in the volatility of futures prices as maturity increases. The observed convenience yields in future contracts are highly significant, in particular for the Kyoto commitment period starting in 2008. Hence, the futures price for 2008-2012 futures currently exceeds the expected spot price at maturity. We further investigated models forexplaining the level and price dynamics of convenience yields. We find that a two-factor model using current the spot price level and its volatility as explanatory variables explains a high fraction of observed convenience yields for the Kyoto period. We further find a significant positive relationship between the spot price level and convenience yields while the spot price volatility exhibits negative correlation with convenience yields. We further find that the daily changes in the convenience yields for the pilot period exhibit heteroscedasticity and the dynamics can be models using a MA(1)-GARCH(1,1) approach.

We conclude that emission allowances price behavior in the spot and futures market is substantially different to those of other commodities. Market prices indicate changing dynamics in the term structure and volailitiy of spot and futures prices. However, models using the spot price level and volatility as explanatory variables provide good results on explaining the behavior of convenience yields at least for the Kyoto period. In terms of market behavior, the current contango market situation with negative convenience yields can be interpreted as expectations on the price risk of CO_2 emissions allowances and the notion of forthcoming new allocation plans in the EU for the Kyoto period.

Acknowledgements

This work was supported by Deutsche Forschungsgemeinschaft through the SFB 649 'Economic Risk' and by DAAD and KBN grant no. D/05/11810.

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This research was supported by the Deutsche Forschungsgemeinschaft through the SFB 649 "Economic Risk".

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