An Empirical Examination of the EUA Emission Rights Market

Investigation of the price dynamics of EUA future contracts

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Abstract

Since the introduction of an international market for emission rights researchers are still trying to determine the price dynamics of these instruments, which are traded in a market that bears no resemblance to any other equity or commodity market to date. In our thesis we apply econometric analysis and derivative theory to find factors that affect the prices of EUA futures. We use regression analysis and ARIMA modeling, combined with ARCH and GARCH modeling for error term variance. Although we find that major equities and interest rates are weakly correlated with EUA returns, we can establish that when modeling EUA future returns with a threshold GARCH process we obtain significantly better results than previous studies. Since the sample period is largely affected by extreme observations during the initial trading period we also broke the sample down into sub-periods and repeated the tests. Our findings suggest that while the initial sub-period shows significant autoregressive behavior, the latter period follows a random walk. We also determine whether the standard cost of carry approach can be applied to link EUA spot and future prices. We find that there are significant convenience yields in the EUA market for the first sub-period, while the second shows no significant convenience yields. We finally conduct ARIMA modeling and test for convenience yield for the first half of 2008. Our results indicate that there is a positive convenience yield of holding future contracts and the autoregressive behavior has diminished, signifying that the market follows a random walk.

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1. Introduction:

To combat the growing issue of global warming members of the OECD countries erected the Kyoto protocol in 1997 to address the issue of the increasingly deteriorating environment. As a result, the right to emit greenhouse gases became a tradable asset and by the end of 2006 the world market for tradable emissions rights represented an estimated value of 22.5 billion Euros, with a 345% increase in cleared volume since the introduction of emission rights (Point Carbon, 2007). The question remains, how such emission rights should be viewed; as financial instruments, as commodities, or are they entirely separate bread. Although emission rights bear striking resemblances to financial instruments, they differ in that they do not pay interest, dividends or give the holder the right to some underlying asset. In terms of commodities, emission rights share the properties of being a factor purchased with the intention to consume as an input factor in production. However, they differ in that commodities are value creating whereas emission rights can be viewed more as a tax (Uhrig-Homburg and Wagner, 2006). Because of the very recent development of this financial instrument many have questioned the properties and pricing mechanisms that surround these contracts, and many regulations and policy changes have had radical effects on the prices of emission rights.

1.1. Purpose and contribution

The purpose of this thesis is to broaden the research of the relatively new and unique emissions market. Due to the exceptional nature of contract design, regulatory influence and lacking market knowledge, the carbon market has experienced several market abnormalities which warrant further investigation of the subject. Since the market has only been active for approximately three years empirical research has been slim up to this point in time and our ambitions are to contribute to the ongoing research and apply new models to explain the EUA price dynamics.

1.2. Outline

Our thesis is constructed as following. First, due to the new and relatively unique market characteristics of the carbon market we will begin by providing a background description

(Section 2) of the implementation of an international emissions market. The section will contain a detailed presentation of all market constraints and market instruments that will be relevant for our empirical tests. Next, Section 3 will present the economic theories and models that will govern our empirical tests and previous research within the topic, which will lay the foundation for our hypotheses (Section 4), which build upon our expectations based on previous findings and the theoretic framework. The methodology, a presentation of our chosen variables, and motivation for exclusion of variables will be presented in Section 5. Section 6 will present our results from the full sample and sub-samples while Section 7 will present our conclusions on the subject, economic implications of the results, as well as suggestions for future research within the carbon market.

2. Background

To fully grasp the mechanisms that control the trading of emissions right, one must first review the underlying source of this instruments birth. We will begin by presenting a brief summary of the Kyoto protocol and how it has dictated the design of emissions rights, as well as presenting how and where emissions rights are traded, and finally presenting the different financial instruments that have been developed.

2.1. The Kyoto protocol

In light of the escalating deterioration of the global environment and vastly increasing pollution, the world's major emitters of greenhouse gases erected the Kyoto protocol in December 11th 1997, at the third Conference of the Parties (COP 3) to the UNFCCC in Kyoto, Japan. The main purpose of the agreement was to reduce greenhouse gas (GHG) emissions by reducing the emissions of carbon dioxide and five other gases[1]. The limits agreed upon in the Kyoto protocol are country specific, with ranges between 8% reduction to 10% allowed increase in emissions, compared to each country's 1990 emissions level (UNFCCC, 2008). The emission caps are set by the EU Directive, where the individual member states in turn allocates emission rights to the domestic emission intensive industries through a national allocation plan (NAP). Although the agreement specifies a gradual reduction in the NAPs, the NAPs during the phase I period (2005 - 2007) were intentionally generous in order to provide

[1] These gases include methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride.

a “practice round” for member states before the Kyoto commitment period commenced (2008-2012). This action led to several market abnormalities during the initial trading phase (Toivonen, 2006). Although the member states allocated the majority of emissions rights free of charge, during the first commitment period 5% of emission rights were allowed to be auctioned off, and 10% during the second period (2008 – 2012). While these methods have not previously been used in a wide extent, it may have significant implications on future emission prices.

In line with the specifications of the Kyoto protocol countries have been divided into Annex I, Annex II and developing countries. Annex I countries represent the industrialized countries (as of 1992) which have formal emissions targets. In addition, a subgroup of the Annex I countries are defined as Annex II countries (see Appendix A), who have the right to help developing countries reduce their emissions by engaging in emission reducing projects (which is further discussed under the Clean Development Mechanisms section). Developing countries have no formal emissions targets, but can apply to become Annex I countries once they have achieved a certain level of development. As of 2008 approximately 175 countries have ratified the Kyoto protocol, with the United States and Kazakhstan being the only major countries that have not ratified the agreement (UNFCCC, 2008). Despite intensive negotiations with the United States, who accounted for approximately 36% of all GHG emissions in 1990, they are still reluctant to ratify the agreement due to the risk of severe adverse impact on their emissions intensive industries and economic consequences thereof (Babiker et al., 2002). EU states have also agreed to continue emission reductions following the Kyoto commitment period, where 12% reductions over the Kyoto levels have been agreed upon between 2013 and 2020 (Daskalakis & Markellos, 2007).

To facilitate a market priced instrument, the Kyoto protocol set the standard for exchange traded emissions rights, where countries/companies can openly trade emission rights to match their holdings according to their expected emission levels. The main objective is to reduce emissions on a global basis, albeit by setting national emission targets. To reach the objective three flexible mechanisms have been erected to facilitate the global reduction of greenhouse gases. The results of these mechanisms create the underlying emission credits that have now grown into a substantial tradable instrument.

2.1.1. International Emissions Trading

Article 17 of the Kyoto Protocol specifies the most relevant mechanism to reduce worldwide emissions which is the engagement in international emissions trading (Babiker et al., 2002). Emissions trading states that companies that can reach their required emissions targets with relative ease can openly trade emissions rights and sell to companies that have more difficulty in reducing their emissions. Thus, on a worldwide basis emissions will be reduced and the more effective countries will receive a monetary gain from such actions, thus providing intrinsic incentives. As of 2005 a comprehensive exchange based trade of emissions rights has evolved as a shift in paradigms from the previous command-and-control system. Based on the EU Directives, each member state is required to meet or fall short of the emission targets set for the commitment periods; the pre-commitment period (2005 – 2007) and the latter being the official Kyoto commitment period (2008 – 2012). The allocation of emission rights takes place in the end a February each year. On April 30th the following year companies are obligated to submit emission rights corresponding to the precise amount of emissions incurred. During the course of the year firms will adjust their portfolios of emission rights based on the expected emission volumes. Should a firm fail to meet their obligations the EU Directive has specified penalty charges in the amounts of 40 Euros per ton during the pre-commitment period and 100 Euros per ton for the Kyoto commitment period. The fines do however not alleviate the firms to meet their obligations, where the deficit in emission allowances will be deducted for the following year. This thus creates motives for companies to engage in emissions trading.

The major players in this market are, unsurprisingly, the major emitters of GHG, comprising of combustion installations exceeding 20 MW, refineries, and coke ovens as well as the metal, pulp and paper, glass, and ceramic industries (Uhrig-Homburg & Wagner, 2006). In addition to the cap-and-trade the baseline-and credit-system is also used for companies to meet there emissions targets. In essence, polluters that are not subject to emissions caps can obtain credits by voluntary reducing their emission below a pre-specified baseline. These credits can then be traded or prematurely written off, thus lowering the total supply of credits available.

2.1.2. Joint implementation and Clean Development Mechanism

Although not the primary focus of this thesis, we will provide a brief background on the secondary flexible mechanisms stated in the Kyoto protocol, with the purpose of providing an in-depth understanding of the emissions market. Article 6 of the Kyoto protocol states that countries within the Annex I region (i.e. developed counties) can engage in emissions reducing activities in other Annex I countries if the costs of reducing the domestic emissions are “too” costly. By engaging in joint implementation (JI) projects the executing country will receive Emissions Reduction Units (ERU) which represents the allowance to emit one ton of carbon dioxide, where the equivalent amount of emission credits are deducted from the party receiving the benefits from the project. As a consequence of this act, many counties are eluting the commitment to reduce their domestic emissions by engaging in JI projects in countries where it is considerably cheaper to reduce emissions (UNFCC, 2005). However, reports from the IPCC (International Panel of Climate Change) predict that European OECD countries that are engaging in JI projects (as well as Clean Development Mechanisms, CDMs) will lose approximately 0.82 % of GDP in the year 2010 versus 0.37 % with only domestic emission reducing activities, thus rendering it as a costly approach to reduce emissions (IPCC, 2008).

In addition to JI projects, Article 12 of the Kyoto protocol specifies that Annex II countries can engage in emission reducing activities in developing countries through the Clean Development Mechanism (CDM), thereby receiving emissions credits. More specifically the CDM states that Annex II countries can, given the consent of the host developing country, engage in emission reducing activities which would not have been undertaken in the absence of the initiative from the Annex II country. Such projects may constitute construction of more environmentally friendly power production plants and reforestation. After evaluating the emissions reductions resulting from the project, the Annex II country is awarded Certified Emissions Reduction rights (CERs) which can be traded in the open market or used to comply with the annual emissions target (UNFCC, 2008)[2]. The CDM bears striking resemblances to the JI projects, where the key difference is the recipient of the CDM projects are developing countries, whereas the recipient of the JI project is classified as an Annex I country.

2.2. Banking restrictions between phase I and phase II.

To fully understand the extraordinary events that have taken place in the carbon market, one must delve into the restrictions which have had monumental effects on emission prices. The

[2] It should be mentioned that CDM projects do not include any actions which aim to reduce emissions by the usage of nuclear power (Raizada et al, 2006).

division of emissions trading between the pre-commitment period and the Kyoto commitment period has given rise to an unorthodox market structure with banking restrictions. Banking refers to firms being able to save excess emission rights for consumption in later years, or equivalently, borrowing future EUAs for consumption in the current year (albeit restricting the future borrowing to one year). As such, companies are allowed a certain amount of flexibility in adjusting their need for EUAs. However, banking between the first and second commitment period (i.e. between 2007 and 2008) was restricted which has essentially led to two completely different spot markets. Two of the main objectives for implementing the restriction are firstly the fear of companies not reducing their emissions at an acceptable pace (Cason and Gangadharan, 2004). Secondly, at the time of the ratification of the Kyoto protocol there was much ambiguity over the exact speed and level of emissions during the coming years. As such, the member states feared that too generous emission caps would discourage companies to reduce future emissions if banking would be possible (Cason and Gangadharan, 2004). By restricting the borrowing and lending between the 05-07 and 08-12 phases the emission market has encountered several price distortions leading to an abnormal price evolvement. Furthermore, since new spot EUAs were introduced in February 2008 the future contracts with maturity in December 2008 and beyond were traded in the pre-commitment period without an underlying spot price. Consequently, the banking restrictions results in unprecedented low correlation between 08-12 futures and that of spot (Daskalakis et al., 2006). Unlike the European carbon market, the Clean Air Act Amendment (CAAA) in the U.S, which introduced the market for tradable SO2 emission rights, prevented these market distortions by enabling inter-phase banking, where the market has experienced less structural breaks and higher liquidity (Paolella et al, 2006). Alberola and Chevallier (2007) find that the banking restrictions show significant effects on the efforts to reduce emissions. Although the banking restrictions have made price modeling extremely difficult the market is beginning to mature. Furthermore, banking between the Kyoto commitment period and the post-commitment period (2013 – 2020) will not be restricted, thus we do not expect any future abnormalities of the same magnitude (Daskalakis & Markellos, 2007).

2.3. Exchanges

Due to the significance of emission trading and the relative unique properties of the emissions market a detailed description of the exchanges and market instruments is warranted. In order to commence a fair trade of emission allowances, the European Union initiated the European

Union Greenhouse Gas Emission Trading Scheme (hereafter referred to as the EU ETS) in January 2005 (Daskalakis & Markellos, 2007), which was based on Directive 2003/87/EC and entered into force on 25 October 2003 (Official Journal of the European Union, 2003). The purpose of the EU ETS was to encourage reductions of greenhouse gas emissions in a cost-efficient manner (COM, 2006) following the directives of the Kyoto Protocol.

Even though forward EUAs were traded over-the-counter in 2003 (Alberola, 2006), the launch of the EU ETS boosted trade and the EU ETS became by far the largest emission market in the world, with a market share of over 97% (Daskalakis & Markellos, 2007). With electronically exchanges, trading emission allowance rapidly became increasingly popular with a traded volume of 260 million emission allowances in 2005, 800 million in 2006 and approximately 1500 million in 2007, representing a fivefold increase from 2005 (COM, 2006). The growing activity in the emission market boosted more sophisticated products from spot, forwards and futures to swaps, options and structured products. However, it should be mentioned that the latter products are very illiquid and have just recently started to become traded on a daily basis. Although previously mentioned CERs and ERUs exist, EUAs are by far the most common instrument to trade over an electronic exchange. The monthly traded volume of this type of contract has increased from around 44 million tons in January 2006 to approximately 190 million tons in January 2008. The other two contracts, which have mainly been traded over-the-counter (OTC) in bilateral forward deals negotiated through brokers (IETA and World Bank CF Research Report, 2007), have recently become electronically traded (Bluenext, 2008). However, since the bilateral market consists of direct company-to-company transactions, the non-transparency makes it difficult to assess the scale of the trade on this market.

There are presently six major emission exchanges that serve under the EU ETS and trade with EUAs, consisting of the Nord Pool in Scandinavia, the Bluenext (previously denoted as the Powernext) in France, the European Energy Exchange (EEX) in Germany, the Energy Exchange Austria (EXAA) in Austria, the Climex (a union of local exchanges) and the European Climate Exchange (ECX) in the Netherlands. A summary of the traded products, exchange properties and the trading hours are presented in Table 1.

Table 1

Summary of major exchanges on the EUA market

Exchange	**Launch**	**Share spot**	**Share future**	**Trading Hours**
Bluenext	2005-06-24	63%	0%	08.00 – 17.00
European Energy Exchange (EEX)	2005-03-09	16%	3%	08.00 – 17.00
Nord Pool	2005-11-02	7%	9%	08.00 – 15.30
EXAA	2005-06-28	~1%	0%	08.00 – 14.10
European Climate Exchange (ECX)	2005-04-22	0%	88%	07.00 – 17.00
Climex Alliance	2005-06-22	14%	0%	N/A

2.4. Instruments

2.4.1. European Union Allowance

Since this thesis will focus on the pricing of EUAs, we will give a comprehensive background to provide a thorough understanding of the market instrument. Although the instruments share many common properties with investment based instruments, EUAs are traded in the commodity market. The instrument is an emission credit issued by the EU ETS where each EUA carries the right to emit one ton of carbon dioxide over a pre-specified commitment period. EUA futures, in contrast to EUA spot, are by far the most liquid and traded instrument, with 92.6% (approximately 1.1 billion transactions) of all traded volume in 2007 being futures[3]. The future contract, which is physically settled three days after expiration, has spot EUAs as the underlying instrument and the contract size corresponds to 1000 EUAs. At any given day, investors can either buy or sell future contracts maturing in December for each year up to 2012, where daily price changes are marked to market. The spot contracts are physically settled the day following the transaction and represented 2.6 % (approximately 30 million transactions) of all traded volume in 2007[4]. The substantially lower volume of trade in the spot market is attributed to the fact the EUAs are only required during the reporting periods, thus not rendering any obvious advantages of holding spot contracts during the proceeding periods. The minimum purchase volume is 1000 spot EUAs. In addition to future contracts and spot contracts, several other instruments are starting to evolve, such as option

[3] Based on calculations using data sourced from European Climate Exchange.
[4] Based on calculation from the five largest European exchanges: ECX, Nord Pool, Bluenext, EEX and EXAA sourced from www.mondovisione.com

futures and swaps. However, as already mentioned these instruments are still highly illiquid and only represent a fraction of the traded volume.

2.4.2. Certified Emission Reduction and Emission Reduction Units

Although the EUA represents the largest exchange traded contract, a brief discussion of CERs and ERUs is mandated. A Certified Emission Reduction or CER is, as previously mentioned, a financial instrument obtained from the Clean Development Mechanism (CDM) projects and issued by the UN. CERs, like EUAs, are also tradable instruments but are designed to be used by Annex II countries to add up their Kyoto targets. Nevertheless they can be used by EU countries, under certain assumptions explained in the European Union's Linking Directive, to increase their EUA amounts (Carbon Positive, 2008). Hence, CERs have the same compliance value as EUAs although they are priced with a discount compared to EUAs (ECX, 2008). There are several argument for the continuously price discount of CERs compared to EUAs such as the restriction to only use 10% of total allowances as CERs for compliance in the EU ETS (IP06/1650, Nov 2006), they are traded on an undeveloped secondary market (Carbon Positive, 2008) and heterogeneity between projects, rendering it difficult to forecast CER allocation. However, a difference in favor for CERs, in contrast to EUAs, is that CERs could be banked between the first and the second phase of the EU ETS (Wolff, 2006), i.e. between 2007 and 2008. CERs future contracts, with a tradition of being only traded over-the-counter, were recently launched on Nord Pool (June 2007) and the Bluenext Exchange (April 2008).

An Emission Reduction Units or ERU follows the same characteristics and rules as a CER but is issued under JI projects and permits the holder to emit one ton of CO_2. The only difference between ERUs and CERs is that an ERU can be substituted within the EU ETS as of 2008 while the CER could be substituted as of 2005 (Wolff, 2006).

3. Theoretical framework

In this section we aim to provide a thorough presentation of the major theoretical framework which is applied in our tests, coupled with findings from previous research. Section 3.1 and 3.2 will review convenience yields and the findings of such in the EUA market. Section 3.3. and 3.4 will give a thorough review of ARIMA modeling and ARCH/GARCH process. The proceeding section (Section 5) will discuss the theory and findings of random walk processes.

To give a summarized overview of the finding relevant for our research, Section 3.6 will present a table of previous findings and their respective sample periods.

3.1 Future pricing and convenience yields

Because of our focus upon the EUA futures market, a brief review of future pricing theory is justified. As with “normal” investment based future contracts, the no-arbitrage assumption states that the relationship between spot prices and futures is simply given by the cost of carry, i.e. the cost of holding the underlying spot (in terms of forgone interest). The relationship results in the following equation:

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

However, in commodity markets future prices and spot prices may differ from the above relationship due to costs and benefits associated with holding the underlying commodity, as opposed to the future contracts. These costs commonly take the form of storage costs, whereas benefits incurred from holding the underlying spot is termed convenience yields (Wei and Zhu, 2006). When comparing spot and future prices, there are several different scenarios of the future price dynamics which should be mentioned. In a situation where the future prices are less than the current spot prices the future market is said to be in backwardation, whereas if future prices are less or equal to expected future spot prices the future market is said to be in normal backwardation. This phenomenon is usually observed in the market for commodities where the holder of the underlying commodity can benefit from the possession of the underlying as opposed to holding the equivalent long future position (Hull, 2006).

However, holding the physical asset involves costs such as storage costs and indirect costs such as interest rate risks. As such, the future price should be higher than future spot prices, under risk neutral valuation, since the holder of the underlying commodity incurs financial risks and storage costs of holding the underlying and should thus be rewarded for bearing these risks. This phenomenon is termed contango. (Hull, 2006)

In a market for production factors, companies will often hold inventories of the production factor to absorb stochastic price fluctuations and stock outs. Previous research has shown that EUAs share more similar characteristics with the commodity market than the market for financial instrument. EUAs, for instance, are purchased as an input in the production process and are exhausted and removed from the market after having been consumed (Uhrig-Homburg & Wagner, 2007). Thus, if EUAs share the same characteristics as other commodities, it may be reasonable to assume that firms will hold a stock of EUAs which would give rise to positive convenience yields, rendering lower futures prices than current spot prices. Since holding a long position in EUAs does not involve any storage costs the convenience yield is given by:

$$(2) \qquad \varphi_{T-t} = S_t e^{r(T-t)} - F_{t,T}$$

where S_t denotes the spot price at time t, r is the continuously compounded interest rate for one year, T-t is the time to maturity and $F_{t,T}$ is the future price of the contract at time t.

3.2 Previous findings concerning convenience yields:

When looking at the commodities market, research has shown that assumptions behind constant convenience yields are rejected. Fama and French (1987) found that the marginal convenience yield varies over time, exhibiting seasonal effects and mean reversion. Hilliard and Reis (2008) elaborate and claim that convenience yields will vary due to competition in storage of the underlying commodity. However, the EUA market cannot be classified as an ordinary commodity market, where there is no rationale behind any assumptions of storage costs.

Trück et al (2006) pioneered by examining the presence and variation of stochastic convenience yields in the EUA market. When examining the relation between the spot and future market, 2005-2006, the authors found that the future market alternated between an initial state of backwardation for the October 2005 to May 2006 period, and contango from May 2006 onwards. The shifting characteristics gave rise to convenience yields switching from positive to negative.

Milunovich & Joyeux (2007) follow the same line of reasoning, where they prove empirically that none of the future contracts tested (December 05-08 contracts) are priced according to the cost-of-carry approach. Furthermore, the authors test for significant convenience yields for different future contracts. The intuition is that holding the underlying spot gives rise to a convenience yield, as opposed to holding a future contract with distant maturity. However, in the short run (i.e. futures maturing with a year) there should be no significant convenience yield, which is revealed by the authors' tests.

Daskalakis et al (2006) differ in their conclusions, although agreeing with Milunovich & Joyeux (2007), who find that there is no statistically significant convenience yield for intra-period futures. However, contrary to Milunovich & Joyeux (2007) they argue that the cost-of-carry approach is well suited for modeling the relationship between the underlying spot and corresponding future contracts. When examining the inter-period futures the authors find a significant mean reverting convenience yield, however we will argue that such assumptions may be invalid due to the fact that the futures with maturity in the Kyoto commitment period follow a different stochastic process than the spot prices observed during the pre-commitment period.

3.3. Econometric framework – ARIMA, ARCH and GARCH models

3.3.1. ARIMA modeling

As an alternative approach of trying to determine variations in a dependent variable using exogenous explanatory variables, Box-Jenkins developed the Autoregressive Integrated Moving Average (ARIMA) model. When employing an ARIMA model one uses lagged observations of the dependent variable (denoted as y_{t-1}) and lagged residuals (denoted as ε_{t-1}) to model the variations in the dependent variable. As such, the ARIMA model incorporates an autoregressive dimension, consisting of p lags of the dependent variable and a moving average dimension, consisting of q lagged errors. Since using first differentiate variables in an ARMA(p,q) model is equivalent to using non-differentiated variables in an ARIMA(p,d,q) model (and setting the differentiation to 1) we have chosen to present an ARMA(p,q) process, as depicted in the equation below, where α denotes the intercept and ϕ denotes the coefficient estimates (Seddighi, et al, 2000).

(3) $$y_t = \alpha + \phi_1 y_{t-1} + \phi_2 y_{t-2} + ... + \phi_p y_{t-p} + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + ... + \theta_q \varepsilon_{t-q} + \varepsilon_t$$

The ARIMA model (or ARMA model using first differentiated variables) proposes a certain level of differentiation, where using the first difference of the dependent variable is usually adequate to obtain a stationary sample. Since economic time series will usually exhibit a trend, the lack of stationarity will cause t-statistics and R-squares to be inapplicable with spurious results (Seddighi et al, 2000).

It should also be mentioned that ARIMA modeling is basically measurement without theory. Thus, ARIMA models are not adequate when analyzing economic relationships and are more suitable as benchmarks for economic forecasts.

To evaluate the most efficient ARIMA model one commonly uses two information criteria. Firstly, the Akaike's information criterion (hereafter referred to as AIC) measures the goodness of fit of the estimated statistical model and is defined by the following formula:

(4) $$AIC = \ln \hat{\sigma}^2 + 2k / T$$

where $\hat{\sigma}^2$ is the estimated residual variance, k is the number of parameters in the model and T is the total number of observations. The AIC penalizes the inclusion of excessive parameters, where the model with the lowest AIC value is the preferred model. Thus, a model with a low AIC value makes the best use of the fewest amounts of parameters.

The Bayesian information criterion (hereafter referred to as BIC), also known as the Schwarz criterion, is an asymptotic result derived under the assumption that the data is exponentially distributed. The model with the lowest BIC value also implies a better fit of the explanatory variables. The BIC is given by the following formula:

(5) $$BIC = \ln \hat{\sigma}^2 + (k / T) \ln T$$

where $\hat{\sigma}^2$ is the estimated residual variance, k is the number of parameters in the model and T is the total number of observations. The BIC is a harsher test than the AIC and gives higher penalty to the inclusion of additional parameters. The difference between the two criteria is that the AIC tends to select large models whereas the BIC tends to select small models.

3.3.2. ARCH process

Autoregressive conditional heteroscedasticity (ARCH) is a method of modeling the error term variance which assumes that when conducting autoregressive models, the variance in time *t* is conditional on the variance in *q* lags. Thus, the underlying assumption is that the variance is not constant over time (Engle, 1982). The application of an ARCH process thus accommodates for heteroscedasticity, or time varying variance, by setting the error term variance equal to the weighted lagged error variances, where the weights are reduced as time increases (following the assumption that the most recent variance should exert the highest impact on the current variance). The ARCH process is given by the following equation:

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^{q} \alpha_i u_{t-i}^2 \tag{6}$$

where α_0 denotes the constant, α_i denotes the weight of the error variance (u_{t-i}^2).

3.3.3. GARCH process

Bollerslev (1986) developed an extension of the ARCH process, termed the generalized autoregressive conditional heteroscedasticity (GARCH) process, where the variance is comprised of the previous period's variance *and* the fitted variance from all previous periods. The GARCH(*p*,*q*) model is given by the following equation:

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^{q} \alpha_i u_{t-i}^2 + \sum_{j=1}^{p} \beta_j \sigma_{t-j}^2 \tag{7}$$

The use of a GARCH(1,1) has several advantages over the ARCH since the GARCH(*p*,*q*) also takes into consideration the *lagged* conditional variances (given by $\beta_j \sigma_{t-j}^2$) as opposed to the ARCH(*q*) process that only uses the conditional variance as a linear function of the past sample variances. By using a GARCH(1,1) process one can reduce the heteroscedasticity and also use less parameters than with an ARCH process, thus reducing the AIC and BIC values. Also, the use of a GARCH process takes into consideration the clustering of volatility, just like the ARCH process, which is important since financial time-series often show evidence of asymmetric volatility, where certain periods exhibit higher volatility than others.

3.3.4. Extensions of the GARCH process; GJR-GARCH

Glosten, Jagannathan and Runkle (1993) further elaborated on the development of the GARCH models taking into consideration asymmetric shifts. The critique against the standard GARCH model was that the model was too restrictive and did not allow the conditional variance to change asymmetrically depending on the sign of the shock. Thus by modifying the standard GARCH model to account for asymmetric shifts one can obtain more credible results, with a reduction in skewness and kurtosis. The GJR-GARCH model is given by the following equation:

$$(8) \qquad \sigma_t^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta_1 u_{t-1}^2 + \gamma_1 I[u_{t-1} < 0]u_{t-1}^2 \quad \text{where } I[u_{t-1} < 0] = \begin{cases} 1 \text{ if } u_{t-1} < 0 \\ 0 \text{ otherwise} \end{cases}$$

The effect of a positive shock is equal to α_1 while the effect of a negative shock is equal to $\alpha_1 + \gamma_1$. Thus the conditional variance will react asymmetrically depending on the announcement. Due to the configuration of several statistical packages the model can be modified to show the opposite results, given by the following equation:

$$(9) \qquad \sigma_t^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta_1 u_{t-1}^2 + \gamma_1 I[u_{t-1} > 0]u_{t-1}^2 \quad \text{where } I[u_{t-1} > 0] = \begin{cases} 1 \text{ if } u_{t-1} > 0 \\ 0 \text{ otherwise} \end{cases}$$

Thus, the results should be interpreted in the opposite way, i.e. a decreasing volatility in light of positive news.

3.4 Application of ARCH and GARCH models

Benz and Trück (2008) apply ARCH and GARCH processes to accommodate for heteroscedasticity in EUA spot prices. In accordance with previous findings they find that the returns are autocorrelated and show that an AR(1) process yields the best BIC value for their in-sample computations. Furthermore, to accommodate for volatility clustering in returns the authors find that modeling the error term variance with a GARCH(1,1) process significantly reduces heteroscedasticity. Paolella & Taschini (2006) also find significant heteroscedasticity in the error term variance and also suggest modeling the error term variance with a GARCH(1,1) process. In addition to previous research, Toivonen (2006) also proposes modeling the error term variance of the future contracts with an ARCH and GARCH process, however does not conduct any empirical test for this.

3.5. Findings of random walk

Toivonen (2006) conducts empirical research of EUA future returns and examines the possibility of market inefficiency. Tests reveal that EUA future and spot returns show significant autoregressive behavior, following an AR(1) process. Thus, EUA returns do not follow a random walk. However, when testing for informational efficiency the author concludes that the market does fulfill the requirements of being efficient according to the weak form of the efficient market hypothesis since the past information does not facilitate abnormal returns.

Daskalakis & Markellos (2007) also analyze whether the weak form of the efficient market hypothesis holds for the carbon market, where the authors find significant autocorrelation in prices, suggesting that the weak form of EMH does not hold. The random walk (RW) approach, among others, is applied, where investors take long positions if the price today is above the yesterday’s price. The authors find that the RW investment strategy yields significant long run returns in the spot market. However, since short selling in the EUA spot market is practically impossible investors are limited in their positions.

3.6. Summary of previous research

To summarize the most relevant previous findings, we have included a table over all findings that will guide us in our empirical tests.

Table 2

Summary of previous research results

Authors *Year*	**Sample period**	**Findings relevant for our study**
Daskalakis, Psychoyios, Markellos (2006)	*(24 June 2005 – 22 Dec 2006)*	• Intra-period futures are priced according to the cost-of-carry approach with no significant convenience yield. • Inter-period futures are priced using a Geometric Brownian Motion with Jump Diffusion and a mean reverting convenience yield.[1]
Benz & Trück (2008)	*(3 Jan 2005 – 29 Dec 2006)*	• Logged EUA return exhibit skewness, kurtosis and heteroscedasticity, suggesting an AR(1)-GARCH(1,1) stochastic modeling of the time series.
Trück, Borak, Härdle, and Weron (2006)	*(4 Oct 2005 – 29 Sept 2006)*	• Significant convenience yields for both pre-commitment and Kyoto commitment period futures. • Shift in the market from initial backwardation to contango. • Daily changes in convenience yields are best modeled using a MA(1)GARCH(1,1).
Daskalakis, Markellos (2007)	*(24 June 2005 – 29 Dec 2006)*	• EUA market is not efficient due to short-selling constraints and banking restrictions. • Employing a Random Walk trading strategy can generate substantial returns.
Uhrig-Homburg & Wagner (2007)	*(24 June 2005 – 15 Nov 2006)*	• Futures can be modeled using cost-of-carry approach for sample after Dec 2005. • No significant convenience yields during post Dec 2005. • Significant convenience yields for full sample due to market inefficiencies.
Alberola & Chevallier (2007)	*(1 July 2005 – 31 May 2007)*	• Emission prices do not adequately reflect marginal abatement costs during initial trading period. • Banking restrictions are largely responsible for the dramatic price decrease.
Paolella & Taschini (2006)	*(25 June 2005 – 3 Nov 2006)*	• No relationship between spot and future prices due to inconsistent behavior of the CO2 convenience yield. • GARCH modeling of CO2 return series produces better model fit.
Seifert, Uhrig-Homburg, Wagner (2007)	*(24 June 2005 – 15 Dec 2006)*	• EUA spot prices are linked to companies expected emission levels, as well as penalty costs. • EUA spot prices are martingales, where even though emissions follow a mean-reverting process, EUA spot prices do not.
Uhrig-Homburg & Wagner (2007)	*N/A*	• There should be no storage costs or convenience yields in EUA spot prices due to no advantage of holding spot.
Toivonen (2006)	*(22 Apr 2005 – 22 Mar 2006)*	• EUA future returns do not follow a random walk, showing significant autoregressive behavior. Despite being econometric inefficient, there is no evidence that investors could earn substantial returns with past information, thus rendering the market economically efficient. • Modeling the future returns with ARCH and GARCH models should improve the results (although not tested).
Milunovich & Joyeux (2007)	*(24 June 2005 – 27 Nov 2006)*	• No futures (2005-2007 or 2008-2012) can be modeled using a cost-of-carry approach, suggesting arbitrage opportunities.

4. Hypotheses

4.1. Hypothesis 1

As already mentioned, future contracts are much more liquid than spot contracts. Two reasonable explanations are that EUAs are only required at the end of each year, in order to match the number of EUAs with their emitted CO2, and that EUAs do not need to be stored, indicating that the storage cost of spot EUAs should be zero. Hence we cannot see any obvious advantage of taking long positions in spot EUAs compared to long positions in future contracts. This means that there should not be any convenience yield by holding EUA spot contracts. This leads to hypothesis one, which is stated as:

Hypothesis 1: *There are no statistically significant convenience yields by holding spot EUAs (for the full pre-commitment sample period, first sub period or second sub period).*

4.2. Hypothesis 2

The research of tradable emission rights has been rather slim due to relative short existence of the instruments, consequently leading to difficulties in developing accurate models to explain the movement in spot and subsequently future returns. Although the bulk of the current research suggests that emission rights show low or none correlation with other major asset classes (Kosobud et al., 2005, and Daskalakis, et. al., 2006), no one, to our knowledge, has analyzed the complete Phase I period. The relation between future returns and the return variation of other financial assets is of course important for us in order to determine an appropriate model for EUA future returns. However, it should also be of great importance for investors, traders and hedgers since this fairly new commodity can be used for portfolio diversification (Daskalakis et al., 2006). Our second hypothesis will thus test for the existence of any correlation between the future returns and the returns of the financial instruments in our dataset.

Hypothesis 2: *EUA future returns have no significant correlation with the returns of the major asset classes in our sample (for the full pre-commitment sample period).*

4.3. Hypothesis 3

When testing hypothesis two, we will examine the correlation between future returns and the returns on other assets. However, it should also be of interest to analyze the existence of any autocorrelation between EUA future returns at time *t* and EUA future return previous to time *t*. According to the random walk theory (Fama, 1965) no such relationship should exist since prices should change independent of each other. Several studies have indirectly tested this theory by suggests that EUA prices seem to follow a random behavior and applying different fine-tuned random walk models. For instance, Seifert et al (2006) introduced a stochastic equilibrium model to explain the spot price dynamics while Daskalakis et al (2006) suggested a Geometric Brownian Motion process with Jump Diffusion to explain the random behavior of the EUA spot price[5]. However, Benz and Trück (2007) analyzed the *short-term* EUA spot price dynamics and argued that one should employ an AR-GARCH model for stochastic modeling, declaring a non random walk model (with the same arguments presented by Toivonen, 2006). Hence it is in our interest to test whether the future returns can be explained by a random walk model which leads us to the third hypothesis.

Hypothesis 3: *The variation in EUA future returns is best captured by a random walk model, i.e. the returns in time t are not conditional upon returns in any previous periods (for the full pre-commitment sample period, first sub period and second sub period).*

4.4. Hypothesis 4 and 5

As we have proclaimed earlier, the pre-commitment period exhibits a number of market abnormalities that have had significant impacts on future prices. Events such as the announcement of excessive long positions in April 2006, the banking restriction between the commitment periods and the relative lacking knowledge of the carbon market have all led to extreme results. As such, our two final hypotheses examine the pricing function of EUA future contracts and the market efficiency within the Kyoto commitment period. Since no research, to our knowledge, has been conducted using 2008 data it is of great interest to see if the same conclusion apply for this trading period. Thus, our final hypotheses are:

[5] See Daskalakis et. al. (2006) for further details regarding Geometric Brownian Motion with Jump Diffusion.

Hypothesis 4: *There is no convenience yield by holding EUA spot contracts during the Kyoto-commitment period.*

Hypothesis 5: *The Kyoto-commitment period market follows a random walk behavior.*

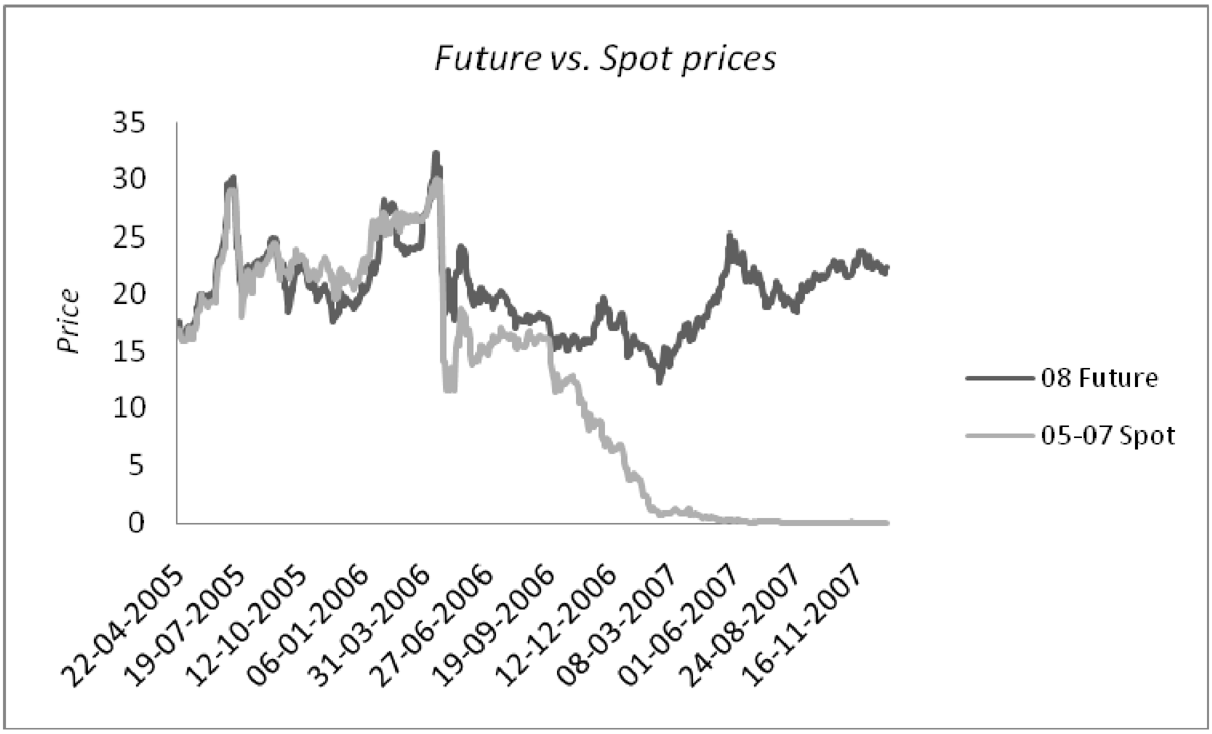
5. Methodology and data collection/formatting

5.1. Data collection

For this thesis we have chosen to select a number of parameters that would likely have some explanatory power in modeling the returns on emission rights. These parameters, which will be discussed later on, have been sourced from Datastream and Powernext while the future and spot EUAs have been obtained from the European Climate Exchange and Bluenext respectively. The dataset has then been modified and tested both in STATA and in some cases SPSS. The reason for analyzing the future return instead of the spot return was due to the specific circumstances concerning the movements of the spot prices in Phase I, i.e. switching from contango to backwardation, excess supply of EUAs and banking restrictions. Hence we opted to focus on the December 2008 futures returns for the pre-commitment period, i.e. 2005-04-22 to 2007-12-31 (a total of 690 observations) and data from the Kyoto commitment period (2008-02-28 – 2008-08-12). Even though the underlying spot for the 2008 future contract did not exist during 2005 to 2007, we felt that the advantage of using December 2008 future in contrast to December 2009-2012 future contracts was that the maturity of this contract was closest to the spot date and may pick up more of the volatility from the 2005-07 spot price movements. This is referred to as the Samuelson effect or the time-to-maturity effect. This is also in line with Trück et al (2006) who found decreasing correlation between future and spot prices as time to maturity increased.

For illustrative purpose, we have compared the December 2008 futures with phase I spot returns as well as logarithmic returns. However, looking at Figure 1, one can see that the spot price diverged from the future price after the market realized that several countries were long by as much as 4% in late April 2006. Hence we decided to split the sample on April 27th 2006, when the spot price dropped by over 35 percent. This is in line with Alberola & Chevallier (2007) who identified the structural break in April 2006 as a market abnormality and thus divide the sample into two separate samples and delete the observations April 25 to June 23 2006.

Figure 1



We are aware of the sensitivity issues when splitting a sample with fairly low amount of observations (627 spot observations), i.e. the choice of "splitting date" may lead to spurious results. On the other hand, we felt that splitting the sample was a necessity in order to give a fair picture of the spot return dynamics and how they have changed. When conducting the comparison we had to delete 64 observations where we had data for the future price but no data on the spot price. For the 627 observations, 209 observations belong to the first sample whilst 418 belong to the second.

5.2. Choice of regression variables

5.2.1. Equity indices

Looking at emission rights through a diversification point of view it is of great interest to examine whether emission rights show any correlation with the major equity indices. As mentioned before, Daskalakis, Psychoyios, and Markellos (2007) performed the first econometric analysis of the spot EUA dynamics and found that due to the low correlation with equity indices, emission rights were well suited as portfolio diversification instruments. Thus, we included the three major equity indices, DAX, FTSE and S&P500, all sourced from Datastream. However, since emission allowances are not isolated to a specific country we also included the S&P World Index and the Financial Times Europe Index in our tests which has also been sourced from Datastream.

5.2.2. Energy indices

The majority of emission rights are allocated to energy producing industries, who contribute to the largest amount of emissions, thus also being the tightest regulated in terms of emissions. Alberola, Chevallier and Chèze (2007) argue that economic growth in this industry should have a direct impact on EUA prices, since one would expect that a higher production growth than baseline projections would result in higher demand on EUAs and vice versa. Hence we have included the Morgan Stanley Europe Energy Index which has been downloaded through Datastream. However, several authors (Bailey (1998), Bunn and Fezzi, (2007), Christiansen et al., (2005), Convery and Redmond, (2007) and Kanen, 2006, Montero and Ellerman (2005) and Paolella & Taschini (2006) have emphasized that energy prices are the most central drivers of carbon prices due to the ability of power generators to switch between their fuel inputs when energy prices changes. This led us to include Brent Crude Oil Index, natural gas price and the Powernext Peak and Base Electricity prices. The oil price is the daily F.O.B.[6] Brent crude oil in $/barrel. However, since EUAs are traded in euro the oil price series was converted to euro using the daily USD/EUR exchange rate provided by Morgan Stanley. The natural gas price is negotiated at Henry Hub at the New York Mercantile Exchange (NYMEX) and is priced as U$/Million British Thermal Units. The time series has also been converted into €$/Million British Thermal Units in Datastream. Finally, the Powernext Peak and Base Electricity are the Day-Ahead Auction Prices in €/MWh obtained from Powernext.

5.2.3. Interest rates

Since future prices are determined by the interest rate we opt to include several interest rates in our tests. Since the majority of worldwide emission trading is conducted in Europe, we include the EURIBOR 1 year and 1 week interest rate obtained from Datastream, as well as the three month LIBOR interest rate.

[6] F.O.B. is short for ”Free on Board”.

5.3. Variable specification

Since the variables in our dataset cover a large range of values we converted the EUA future prices into a natural logarithmic series, denoted as p_t[7]. The variables were tested for unit root using the Dickey-Fuller test which revealed that we could not reject the null hypothesis of no unit root for most of the variables[8]. The natural logarithmic series is therefore converted into a first differentiated natural logarithm series, defined as Δp_t[9], making the series stationary which is needed when testing for the different autoregressive models (Toivonen, 2006). The differentiated natural logarithm series then express the changes in the natural logarithmic series as proportional changes in the actual price, which also can be interpreted as the daily EUA return at time *t*.

5.4. Excluded variables

Although we can identify several influential variables that may have significant effects on the EUA prices and returns, we have been forced to exclude a number of variables due to reasons which will be briefly discussed. First off, several previous studies have identified weather conditions as a major determinant in EUA prices (see Uhrig-Homburg & Wagner 2006 for further details). Periods characterized by higher-than-normal average temperatures will decrease demand for power, subsequently leading to lower power production and emissions. Although the significant impacts, there lies severe difficulties in constructing an appropriate weighted average for the relevant sample area, resulting often in statistical insignificant results (Alberola & Chevallier, 2007). However, by using future prices we eliminate many of the short run impacts caused by fluctuating weather conditions, which would have larger affects on spot prices. Furthermore, economic growth and technological development in emission reductions are also significant variables in explaining the price movements in the EUA spot and future market. While we believe that economic growth can be proxied by equity indices and oil prices, technological enhancements with the purpose of reducing emissions and its effect on emission prices is extremely difficult to determine, as well as when these changes have an effect on EUAs. Although previous research has suggested that EUA

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[7] Where p_t is defined as $\ln(P_t)$ and P_t is the price of the EUA future at time *t*.

[8] Except for Peak and Base Electricity, the Morgan Stanley Europe Energy Index and the S&P World Index.

[9] Where Δp_t is defined as $p_t - p_{t-1}$

prices are directly linked to firms' marginal cost of technological emission reducing activities (see Chesney & Taschini (2008) and Seifert, Ulhrig & Homburg (2007)), determining a monetary value for the impact on EUA prices is infeasible.

The release of news concerning the emission reports has had a monumental effect on EUA prices. As such, investors and market participants view this as the most important effect in determining EUA price dynamics (Daskalakis & Markellos, 2007). However, due to the large dispersion of news over several dates it is difficult to control for this factor in econometric testing and create dummy variables that capture these effects (Toivonen, 2006).

Lastly, although we recognize that political decisions concerning the market for emission rights has an extremely significant impact on prices, we cannot include such a factor because of the unpredictability of such events occurring (Benz & Trück, 2008).

5.5. Selection criteria

As presented in the theoretical framework section, researchers often use either AIC and/or BIC values to measure the goodness of fit of their estimated models. In this thesis we have opted to select our estimated models based on the lowest BIC value. This is firstly due to the fact that when we split the sample into sub periods, as well as using the limited data from 2008, we indeed have a fairly small amount of observations. Since AIC tends to select larger models compared to the models selected by BIC we will sequentially loose important degrees of freedom. Secondly, we believe that the model should not include variables that explain less than what the average variables already explains, thus favoring the use of BIC over AIC. Finally, using a selection criterion that is more parsimonious will steer us in the direction of not selecting models with absence of economic intuition. For instance, if we were to base our selection criterion on AIC values there is a possibility that the chosen model has, for instance, three autoregressive and three moving average lags. Although such a model may prove to exhibit the highest explanatory power, it may lack in economic intuition. Nevertheless, when conducting our tests we will present both the AIC and the BIC values for each model but the final selection is completely based on the BIC values.

6. Results and analysis

6.1. Results and analysis from hypothesis 1

"There are no statistically significant convenience yields by holding spot EUAs (for the full pre-commitment sample period, first sub period or second sub period)."

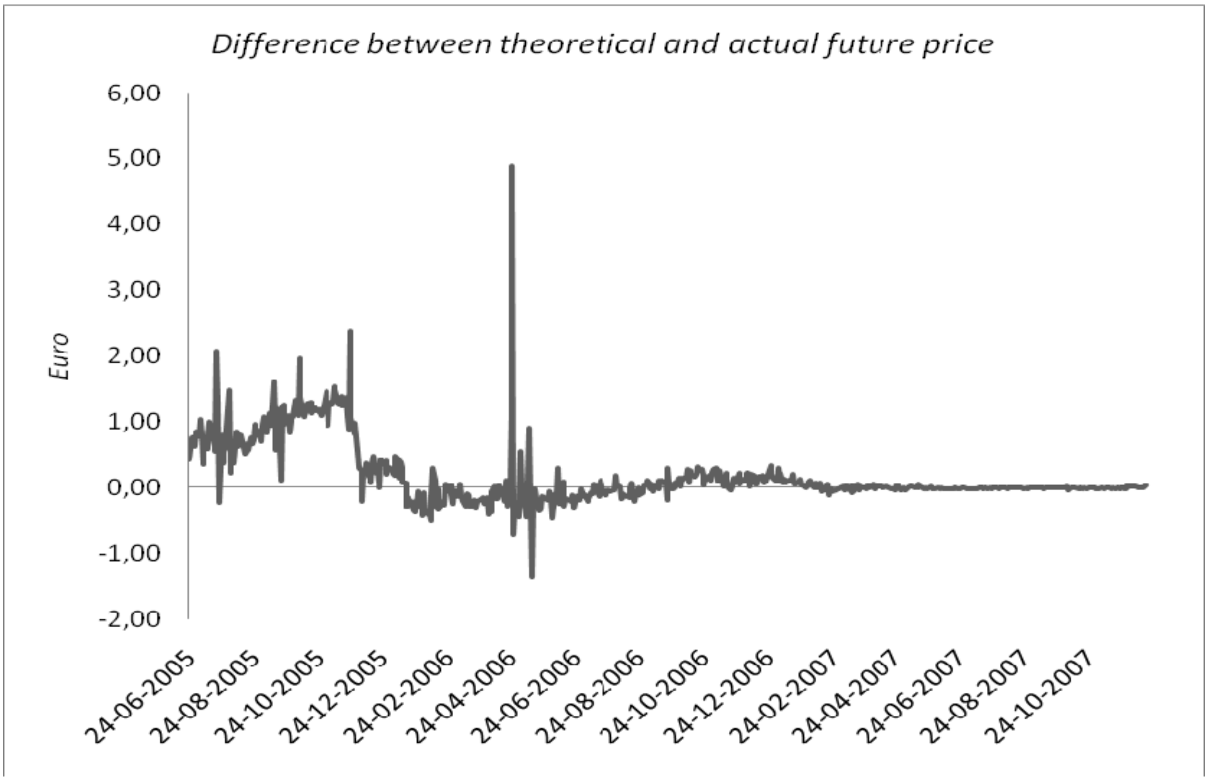
In order to test whether there exist a positive or negative convenience yield for the full sample we had to use data for dates where the spot prices were available. Since the December 2008 future contract only had spot data from February 28, 2008 and forward we had to use the December 2007 future contract and compare it with the underlying spot from April 24, 2005 to December 17, 2007[10]. We then calculated the theoretical future price by using the standard future pricing formula found in Section 3.1:

$$F_{t,T} = S_t e^{r(T-t)} \quad (10)$$

Here we explicitly made four assumptions. The first assumption was that the one year EURIBOR interest rate is used to determine the future prices. The second assumption is that the interest rate changes on a daily basis, i.e. not constant for the full sample period. The third assumption is that the future contract is quoted on a continuously compounded basis. We were also required to make a fourth assumption concerning the market price of risk for the spot price. Hence we simplified and assumed that the price of risk for S_t is constant over time. The actual future price was then deducted from the theoretical future price. The output is displayed in Figure 2.

[10] Because the December 2007 future contract was settled on December 17th we use it as the cut-off date.

Figure 2



As shown in Figure 2, the difference between the theoretical and actual future price is positive for the most part in 2005, indicating that the actual future price is too low, i.e. in normal backwardation. However, in the beginning of 2006 the trend reverses indicating that the actual future price is higher than it should be, i.e. in contango. This is in line with Paolella and Taschini (2006) who also found that the CO2 market was in contango during 2006.

After the supposedly leakage of information in late April 2006, the spot price fell more than the future price hence we can see the extreme value in the figure. Thereafter we can see that the difference between the theoretical and the actual future prices gradually diminishes as we come close to maturity.

Bearing Figure 2 in mind we tested whether the result could be somewhat related to a shifting convenience yield. To test this we extracted the implied convenience yield δ by working backwards from the same future pricing formula as above but here we included the convenience yield:

(11) $$F_{t,T} = S_t e^{(r-\delta)(T-t)}$$

The implied convenience formula then becomes:

$$(12) \qquad \delta_t = r_t - \frac{\ln(F_t / S_t)}{(T - t)}$$

In addition to the assumptions made before, we added two more assumptions; (1) the price of risk for δ_t is constant over time and (2) there are no storage costs. As it turned out, the implied convenience yield was shifting over time and in scale. Thus we felt compelled to split the sample into two halves and delete the last observations in the sample from June 29, 2007 and forward due to increased intervals of non-traded days with unreasonable extreme convenience yield values[11]. The output from the two subsamples is presented in Figure 3 and Figure 4.

Figure 3

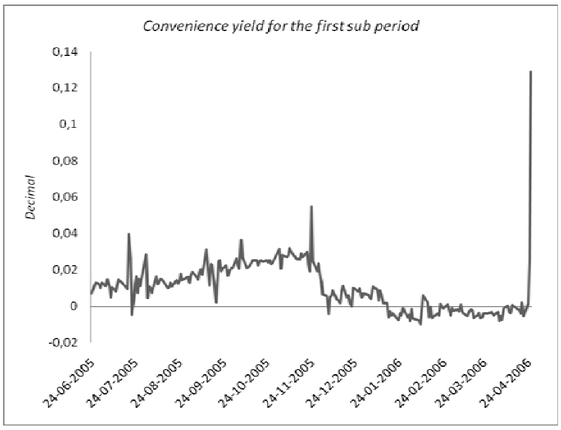
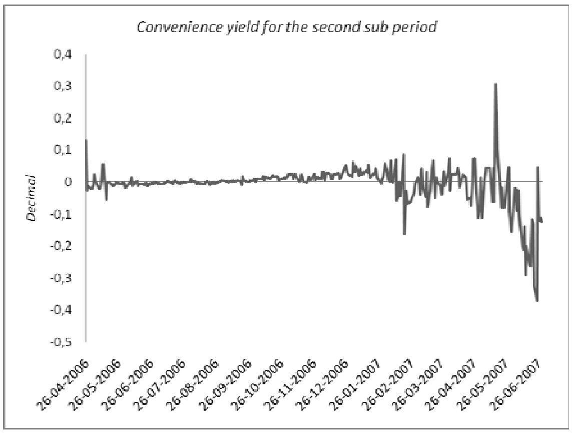


Figure 4



Looking at Figure 3 we do see that the implied convenience yield is positive in the beginning of the sample with a maximum value of 5,4 %. It then turns negative until the extreme observation at the end of the sample which corresponds to the leakage period in late April 2006. In Figure 4, which is in another scale, we can see that the convenience yield becomes more volatile at the end of the period with a tendency of being negative. Bearing both figures in mind, the convenience yield seems to evolve somewhat randomly. To test this we performed a Dickey-Fuller test for unit root in the convenience yield for the whole period (2005-06-24 to 2007-06-29). The test revealed that we could reject the null hypothesis of no unit root at a 5 % level.

[11] Convenience yield values ranging up to 50600%

Similar results were found by Trück et al (2006) who argues that the convenience yields for the phase II futures can be explained by the 05-07 spot price levels and volatility. However, we find the validity of their results to be questionable since the future contracts that mature during this period are based on spot prices that did not exist at that time. The same authors also claim that the negative convenience yields observed in the latter sample period are associated with the expectations on the price risks associated with CO2 emission allowances, thus inducing a higher future price than spot price. We will argue that such a notion may have been a feasible explanation during the relative immaturity of the CO2 market, since the observed extreme convenience yield for the proceeding period is more an effects of banking restrictions. Hence it is simply a sign of the initial market inefficiency during the first trading years. This, coupled with an illiquid spot market, provided several "arbitrage opportunities" which are masqueraded as convenience yields. Thus, applying the cost-of-carry approach may result in positive or negative convenience yields, which may not be valid. However, it should be mentioned that the stochastic convenience yield phenomenon is not unique. Gibson and Schwartz (1990) analyzed the oil spot price in relation to the future price and also found that the convenience yield of oil evolves stochastically.[12]

Even if the convenience yield evolves stochastically over the full sample period we will argue that it is not reasonable to assume that we would have these extreme fluctuations of the convenience yield at the very end of the period (i.e. after June 29th 2007), even if one would assume that we have storage cost. Therefore one should bear in mind that we are actually not explicitly testing whether a convenience yield exists but rather testing whether our pricing assumptions and models for EUA futures contracts are valid. Thus we will argue that the existences of the extreme deleted values might be due to wrongfully stated assumptions, such as using LIBOR instead of EURIBOR or monthly interest rate instead yearly. Further explanations may be transaction costs, bid-ask spreads, short-selling constraints, uncorrelated movements in the future and the spot price, liquidity concerns, and/or the uniqueness of the market. Investigating the transaction cost and bid-ask spread is beyond the scope of this thesis but we can nevertheless illustrate the liquidity of the spot contract and how it changes over time. Looking at Figure 5, we can see the decreasing intensity of traded volume in spot contracts at the end of the sample period. There are several days at the end of the sample

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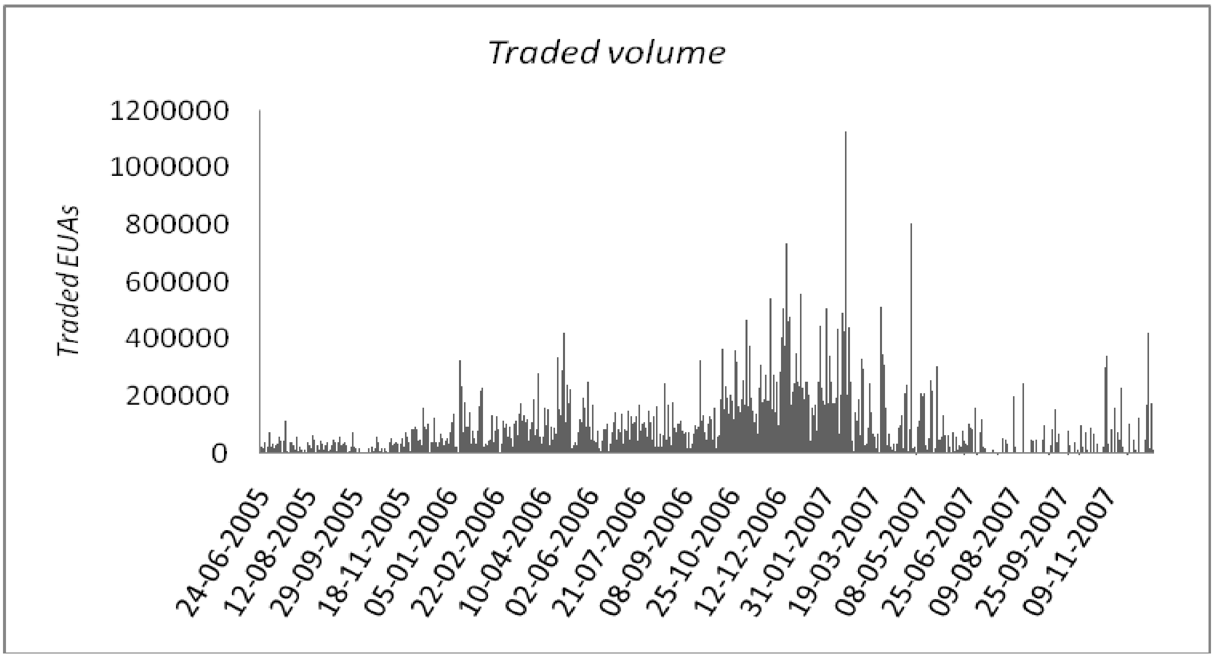
[12] Gibson and Schwartz (1990) also found strong evidence of a mean reverting convenience yield changing from positive to negative. They on the other hand assumed storage cost which in our case is assumed to be zero.

period that we do not have any trade at all. This, in combination to liquid trade in future contracts, may lead to miss-pricing, which affects the implied convenience yield. However, when testing whether we have uncorrelated movements between spot and future contract the obtained correlation coefficient was 0,999 indicating that this is not the case.

Figure 5



Next, in concordance with hypothesis one, we tested if this shifting convenience yield was significant different from zero using a one-sample t-test and testing the hypothesis below:

Full sample period

$H_0 : \delta = 0$ for $0{,}471 \leq (T - t) \leq 2{,}485$

where 2,485 represents the number of years to maturity from the first observation (June 24th, 2005) and 0,471 represents June 29th, 2007, where we decided to cut the sample due to extreme convenience yields following that date.

The result from the t-test shows that we can reject the null hypothesis of no convenience yield. However, the test also reveals that we can reject that the convenience yield is positive indicating that the convenience yield for the whole period is statistically negative at the 5 % significance level. This is however not surprising due to the magnitude of the negative values at the end of the period compared with the rather minute positive values at the beginning of the period as illustrated in Figure 3 and 4. The economic interpretation of the result is that the illiquid spot market would give rise to trading risk, i.e. it is more convenient to hold liquid future contracts in contrast to illiquid spot contracts.

Due to the magnitud of the fluctuations we also decided to split the sample into two sub periods, consequently testing each sub-period. The hypotheses are as following:

Sub-period 1

$H_0 : \delta = 0$ for $1.647 \leq (T - t) \leq 2{,}485$ years

Sub period 2

$H_0 : \delta = 0$ for $0{,}471 \leq (T - t) < 1{,}647$ years

Once again 2,485 represent the number of years to maturity for the first observation (June 24th, 2005) and 1,647 represent time to maturity from April 26th, 2006 where we decided to split the sample, and the cut-off date for the second sub period is the same as the cut-off date for full sample (0,471). The first subsample had 207 observations whilst the second subsample contained 290 observations. As it turned out, we could reject the null hypotheses for both sub periods at a 5 % significance level, indicating that we do have a statistically significant convenience yield. We were also able to statistically reject a negative convenience yield for the first period (indicating a positive convenience yield) as well as a positive convenience yield for the second sub period (indicating a negative convenience yield) at a 5 % significance level. Although statistically significant, one should ask whether positive or negative convenience yield are economically significant. Since EUAs are only used once a year for compliance purpose we cannot find any arguments that would imply that it should be more convenient to hold spot than future contracts. Hence the positive convenience yield during the first sub period may be statistically significant but not economically significant. Hence, we will argue that the existence of the positive convenience yield may be an effect of market insecurity at the initial launch of EUA trading.

To conclude, given our assumptions we indeed see that we have a negative convenience yield over the full sample period. However, when splitting the sample into two sub periods we find support of having a positive convenience yield for the first period and a negative for the second period, where the latter period ultimately affected the full sample period. Hence we do not find support for hypothesis one of no significant convenience yield for any period. These conclusions are also based on the validity of the cost-of-carry approach as a suitable model for future pricing.

6.2. Results and analysis from hypothesis 2

"EUA future returns have no significant correlation with the returns of the major asset classes in our sample (for the full pre-commitment sample period)."

6.2.1. Correlation between various financial instruments and EUAs:

After establishing that there is a significant negative convenience yield for the full sample period, we proceeded to investigate whether the future returns also are influenced by other major asset classes. As previously mentioned, when looking at the market for emission rights, several previous studies have concluded that this particular asset class differs markedly from other assets thus exhibiting low correlation. Daskalakis, et. al (2007) tested for correlation between EUAs and various equity indices, interest rates and energy prices and found no significant correlation. Kosobud et al. (2005) investigated the American market for SO2, as well as a brief investigation of the European CO2 market, and found similar results, concluding that emission rights are well suited as portfolio diversification instruments. Seifert/Uhrig-Homburg/Wagner (2006) however found that there is a high correlation between EUA spot prices and the Phelix base load future contract (EEX) for power, where the high correlation arises from the fact that the cost of emission rights is already incorporated in the future price of energy, whereas the spot price for energy shows much higher volatility and thus does not correlate as well as future prices. Uhrig-Homburg & Wagner (2007) also find that the fuel price spread between coal and gas shows significant correlation with EUA spot prices. In our tests we have examined correlations with asset classes similar to the ones tested by Daskalakis, Psychoyios and Markellos (2007) although including other variables as well. Displayed below are the variables together with the correlation coefficient with December 2008 future return for the full sample period.

Summary of correlation between EUA future returns and major asset classes

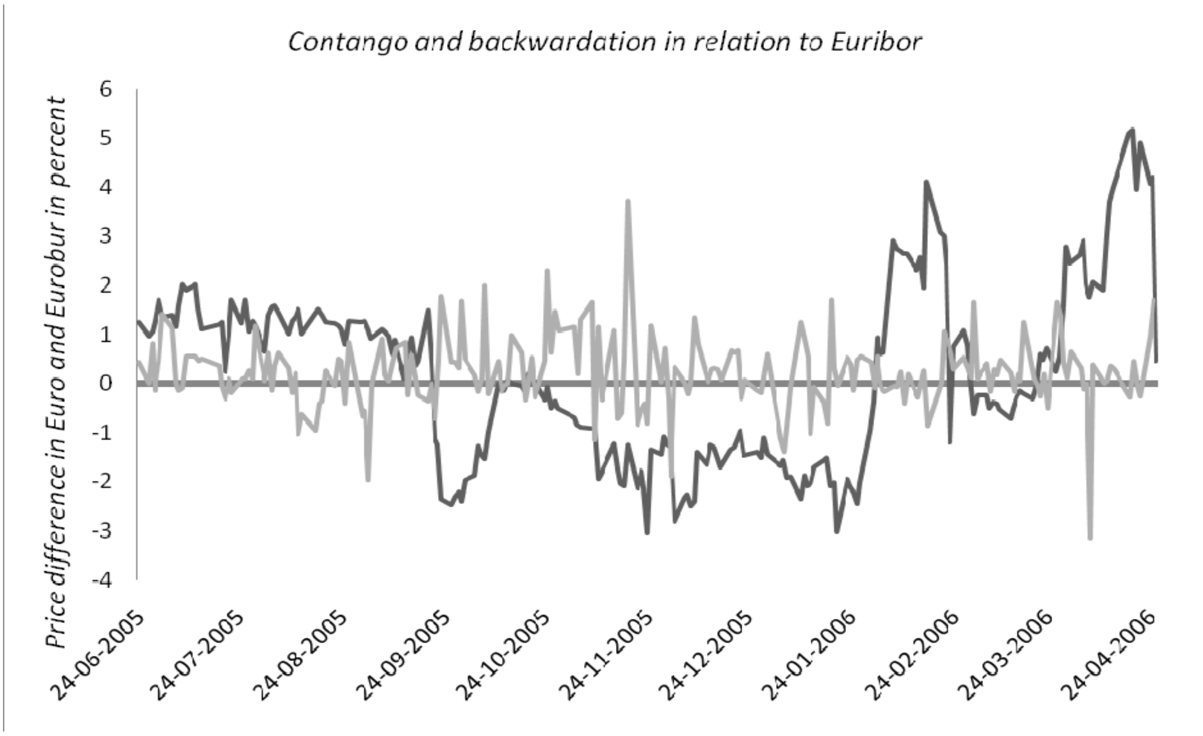
Index	Asset Class	Correlation (%)
DAX	German Equity Market	-0,06
FTSE	UK Equity Market	3,67
S&P500	US Equity Market	-2,83
S&P World Index	Global Equity Market	1,28
FTSE Europe Index	European Equity Market	1,35
Morgan Stanley Europe Energy Index	European Energy Equity Market	13,27**
Brent Crude Oil (€/barrel)	Oil prices	14,53**
Natural Gas-Henry Hub (€/MMBTU)	Gas prices	7,78*
EURIBOR (1 year)	EU Interest rate	-11,73**
EURIBOR (1 week)	EU Interest rate	-0,51
LIBOR (3 months)	US Interest rate	-8,80*
Powernext Base Electricity (€/MWh)	Energy prices	0,57
Powernext Peak Electricity (€/MWh)	Energy prices	1,31

**Correlation is significance at the 5 % level.*

***Correlation is significance at the 1 % level.*

As one can see from the table, the Morgan Stanley Europe Energy Index, the Brent Crude Oil and the 1 year EURIBOR are all significant at a 1 % level and the three month LIBOR rate and the natural gas price at a 5 % level. However, looking at the sign of the correlation coefficients, three are reasonable while two are not. The correlation coefficient of the energy index is positive which is reasonable to assume given that energy producers are the major emitters of CO2. Unexpected growth in this industry would ultimately lead to increased pollution of CO2 and thereby causing a higher demand for EUAs. The oil price, which can act as a proxy for economic growth (Carbonpositive, 2008) has also the correct sign. A slowdown in the world economy would slacken the demand for EUA due to less production. Thus, when oil prices fall, EUA prices should come under pressure. However, one can also see it from another perspective, namely that when the price of oil increases the price of energy increases. Thus there will be an incentive to burn more coal which consequentially increases the demand for EUAs. The latter reasoning is therefore in line with the sign of the correlation coefficient with the natural gas returns. Finally, the one year EURIBOR interest rate, which was used to calculate the convenience yield, and the three month LIBOR rate are not of the correct sign given a no arbitrage assumption. According to the future pricing formula described before, we would expect an increase in future return when the interest rate increases, due to the time value of money. A plausible explanation for observing the reverse relationship could be that the interest rate may be offset by a convenience yield, which as stated before had an impact on Dec-07 future pricing. However, testing this assumption for Dec-08 future contracts proves to be rather difficult since we do not have the underlying spot for this contract and thus we cannot calculate the convenience yield. Nevertheless, if the interest rate is negatively correlated with future returns, we would expect the future price to be in backwaration to a hypothetical spot price when the interest rate return increases. This, once again is difficult to estimate due to the same reason as before, i.e. no underlying spot. However, we can proxy the level of backwardation and contango by calculating the difference between the 2005-07 spot price and Dec-08 futures. Since the Dec-08 future price diverged from the the Dec-07 future in late April 2006, and was rather uncorrelated thereafter, we had to cut the sample on April 26, 2006. The correlation coefficient between the two contracts for the chosen sample period was then 89,87%. The 2005-07 spot prices were then deducted from the Dec-08 future price to display if the Dec-08 future price was in contango or backwardation. We also included the return on the one year EURIBOR where the relationship is illustrated in Figure 6.

Figure 6



Values for the black line above zero indicates that the Dec-08 contract was in contango to the 2005-07 spot while negaive values signifies backwardation. As we can see, the future prices were in contango during the initial period, then swithed to backwardation followed by a more volatile switching period. To be percise, for 51 % of the total observations the future price was in contango, for 48 % it was backwardation and for 1 % the future price was equal to the spot price. What is also evident in the figure is that returns on the EURIBOR (grey line) tends to be high during periods of backwardation and low during periods of contango. This completely contradicts the cost-of-carry theory in future pricing. We fail to provide a definite explanation to this phenonomen but we can conclude that the market seems to be inefficient.

We progressed by computing the partial correlation for the whole sample period between the future return and the various instruments. The result can be seen in Table 3.

Table 3

Summary of partial correlation between EUA future returns and major asset classes

Index	**Asset Class**	**Correlation (%)**
DAX	German Equity Market	3,67
FTSE	UK Equity Market	6,13
S&P500	US Equity Market	-5,49
S&P World Index	Global Equity Market	5,02
FTSE Europe Index	European Equity Market	-9,45*
Morgan Stanley Europe Energy Index	European Energy Equity Market	12,22**
Brent Crude Oil (€/barrel)	Oil prices	5,12
Natural Gas-Henry Hub (€/MMBTU)	Gas prices	2,39
EURIBOR (1 year)	EU Interest rate	-9,17*
EURIBOR (1 week)	EU Interest rate	-0,09
LIBOR (3 months)	US Interest rate	-1,80
Powernext Base Electricity (€/MWh)	Energy prices	-2,56
Powernext Peak Electricity (€/MWh)	Energy prices	3,42

**Correlation is significance at the 5 % level.*

***Correlation is significance at the 1 % level.*

As we see, the oil price and the natural gas price are no longer significant while the FTSE Europe Index turn out to be highly significant. The three month LIBOR rate also became insignificant when the one year EURIBOR rate was included. The result from the Morgan

Stanley European Energy Index as well as the one year EURIBOR stayed the same as the previous result from the simple correlation test. In order to test whether one can predict the movements of future return using other asset classes we developed a model based on the output from the partial correlation test above. The independent variables were chosen on the basis of significance from the partial correlation. Thus the model is formulated as follows:

$$\Delta p_t = \alpha + \Delta Europe_t + \Delta Energy_t + \Delta EURIBOR_t \quad (13)$$

where Europe denotes the FTSE Europe Index while Energy denotes the Morgan Stanley Europe Energy Index. The test statistics from running the regression of the above model can be seen in Table 4

Table 4

Summary of major exchanges on the EUA market

Variables	**Elasticities**	**Std. Err.**	**T**	**P>|t|**
Europe	-0,673427	0,207877	-3,24	0,001
Energy	0,7778263	0,1582137	4,92	0,000
EURIBOR	-0,5955269	0,1958875	-3,04	0,002
Constant	0,0010609	0,0011432	0,93	0,354
R-square:	**Adj. R-square**	**AIC:**	**BIC:**	
0,0481	0,0439	-2897,434	-2879,263	

All the explanatory variables proved to be significant at the 5 percent level, while the constant was insignificant. The result is however not economically reasonable, since we, as already mentioned, would expect an increase in future price when the one year EURIBOR interest rate elasticites increases or vice versa, due to time value of money. Also, FTSE Europe Index and Morgan Stanley Europe Energy index are of opposite signs, leading to inconsistent rationalization of the result. The sign of the Morgan Stanley Europe Energy index is no doubt reasonable but it is the negative sign of the FTSE Europe Index that makes us question the economical intuition of the model, i.e. it is not reasonable to assume that the EUA December 2008 future return decreases by 0,67 % when the FTSE Europe Index increases by 1 percent, given that Morgan Stanley Europe Energy index and the EURIBOR interest rate are held constant. Based on economical reasoning one would expect the sign of the FTSE Europe

Index to be positive, i.e. if the European equity market grows, the economy grows leading to more production and more pollution, thus one would expect an increase in demand for EUAs. However, since it was apparent that the FTSE Europe Index first became significant when other variables where included, we suspect that the Europe and Energy elasticities are strongly correlated. This proved to be correct as the tested correlation between the FTSE Europe Index and the Morgan Stanley Europe Energy Index was 75.64 %. The model was also tested for omitted variables using Ramsey RESET test where we found that the null hypothesis of no omitted variables cannot be rejected. Nevertheless, the R-square from the regression is very low (0.0481) making it an unsuitable model. The AIC and BIC value are only displayed for comparison purpose with other models. To conclude, given the results above, we reject our initial hypothesis of no significant correlation between EUA returns and returns of other asset classes.

6.3. Results and analysis from hypothesis 3

"The variation in EUA future returns is best captured by a random walk model, i.e. the returns in time t are not conditional upon returns in any previous periods (for the full pre-commitment sample period, first sub period and second sub period)."

Although prices of financial time series may show autocorrelation, returns should not be correlated with past returns. Thus, an initial test for autocorrelation is warranted to determine whether EUA future return follow a random walk. When testing for autocorrelation in the EUA future returns our initial tests reveal the there is evidence of significant autocorrelation of 12.81% for both autocorrelation and partial autocorrelation in the first lag for logged returns (see Appendix D). Such evidence would suggest that the EUA futures returns do not follow a random walk, where previous returns have an effect on current returns (in accordance with Toivonen, 2006).

These findings motivate us to test the sample using ARIMA models. When performing ARIMA test with AR(p) lags from zero to three and MA(q) lags from zero to three, we find that an ARIMA(1,0,0) outperforms all other ARIMA models, with a superior AIC and BIC value when examining the full sample period from April 22nd 2005 to December 31st 2007 (full test statistics are presented in Table 5). The results are not surprising since we found significant autocorrelation in the first lag. Furthermore, the AIC and BIC values are lower than for the regression model, thus implying that the ARIMA model better captures the movements in the dependent variable.

Although having established the presence of significant autocorrelation, we also want to determine if heteroscedasticity is present in the EUA future return errors. The plotted residuals in a graph (see Appendix F) indicate presence of heteroscedasticity. To confirm our assumption we conduct a Breusch-Pagan/Cook-Weisberg test for heteroscedasticity where the test statistic shows clear evidence of heteroscedasticity at the 1 % level. However, since the test assumes normal distribution we also conduct a White's test for heteroscedasticity which relaxes the assumption of normality. When conducting the White's test the results show that we cannot reject the null hypothesis of a homoscedastic sample on the 5% level. However, we are able to reject the null hypothesis of a homoscedastic sample on the 10% level indicating that modeling the error term variance with ARCH, GARCH and GJR-GARCH processes may improve the model (results presented in Table 5).

Table 5

Summary of ARIMA models, full sample period

Preferred Model	**AIC**	**BIC**
Regression model	-2897,434	-2879,293
ARIMA (1,0,0)	-2876,887	-2863,282
ARIMA (1,0,2) ARCH(1,1)	-2995,523	-2968,312
ARIMA (1,0,0) GARCH(1,1)	-3040,028*	-3017,351
ARIMA (1,0,0) GJR-GARCH(1,1)	-3049,021**	**-3021,810**

Full test statistics are presented in Appendix E.

**Lowest AIC value was obtain for ARIMA(3,0,3) GARCH(1,1) with AIC: -3045,945*

***Lowest AIC value was obtain for ARIMA(2,0,3) GJR-GARCH(1,1) with AIC: -3054,131*

When modeling the error term variance with a GARCH(1,1) and GJR-GARCH(1,1) we see that not only is the model significantly improved, but our *a priori* assumptions of a GJR-GARCH model are proven to be correct. The GJR-GARCH shows an improvement over the standard GARCH and ARCH processes, thus implying that the error term variance in EUA future returns reacts asymmetrically to different shocks, where positive and negative shocks yields different magnitudes of volatility (full statistics are presented in Appendix E). It is worth mentioning that the AIC values favor other models including more autoregressive and moving average lags than implied by the BIC, but due to the advantages of BIC values (presented in Section 5.5) we will base our conclusions on the BIC values. Thus, conclusively we find that modeling the EUA future returns with an ARIMA(1,0,0) using a GJR-GARCH(1,1) proves to be the optimal model for the full sample period. Although ARIMA modeling has not been applied by other researchers, Benz & Trück (2006) find that when modeling EUA returns with an AR(1) (equivalent to the ARIMA(1,0,0)) GARCH(1,1) the heteroscedasticity widely improved the information criteria. Since our sample consists of a longer time span we are able to pick up more market fluctuations which may have contributed to the discovery of the superiority of the AR(1) GJR-GARCH(1,1). Toivonen (2006) also showed that the EUA future returns are autocorrelation with one lag, and that heteroscedasticity in the error term variance was evident, however, as already mentioned, the author did not explicitly test the appropriateness of ARCH and GARCH models. Conclusively, our results show strong evidence that hypothesis three does not hold for the full sample period, where significant autocorrelation contradicts the random walk hypothesis.

A consequence of rejecting the random walk hypothesis and the normal distribution of EUA future returns (the future return exhibits both high level of skewness and kurtosis, see Appendix B) suggest that the price dynamics do not follow a Geometric Brownian Motion. The violations of these assumptions suggest that the findings of Daskalakis et al (2006) may not be credible. However, Benz & Trück argue that applying an AR(1) GARCH(1,1) process to EUA prices show similar results as in Daskalakis et al (2006) who claim that a GBM with a jump diffusion can be applied to model the price dynamics and take into consideration the large stochastic jumps.

The abnormal market conditions observed during the initial trading period (from the launch of exchange traded EUAs in April 2005 to the first market reports of excess long positions in April 2006) may be the culprit for the observed results. Given that the market has increased in efficiency (Uhrig-Homburg & Wagner, 2007) we repeat the ARIMA modeling for a split sample, consisting of sub period 1 (2005-04-22 to 2006-04-26) and sub period 2 (2006-04-27 to 2007-12-31). Our *a priori* expectations are that while the first sub period should exhibit irrational behavior, the second period should be more stable with lower autoregressive behavior. Our test statistics for the two sample periods are presented in Table 6 and 7.

Table 6

Summary of ARIMA models, sub period 1		
Preferred Model	**AIC**	**BIC**
ARIMA (1,0,0)	-1030,729	-1020,082
ARIMA (0,0,2) ARCH(1,1)	-1118,287*	-1100,542
ARIMA (1,0,2) GARCH(1,1)	-1122,851	-1098,008
ARIMA (1,0,2) GJR-GARCH(1,1)	-1130,952	**-1102,560**

Full test statistics are presented in Appendix E

**Lowest AIC value was obtain for ARIMA(3,0,3) ARCH(1,1) with AIC: -1130,090*

Table 7

Summary of ARIMA models, sub period 2		
Preferred Model	**AIC**	**BIC**
ARIMA (0,0,0)	-1851,716	-1843,584
ARIMA (0,0,0) ARCH(1,1)	-1897,700*	-1885,502
ARIMA (0,0,0) GARCH(1,1)	-1947,865**	**-1931,600**
ARIMA (0,0,0) GJR-GARCH(1,1)	-1946,432***	-1926,101

Full test statistics are presented in Appendix E.

**Lowest AIC value was obtain for ARIMA(2,0,2) ARCH(1,1) with AIC: -1897,988*

***Lowest AIC value was obtain for ARIMA(2,0,3) GARCH(1,1) with AIC: -1948,410*

****Lowest AIC value was obtain for ARIMA(2,0,3) GJR-GARCH(1,1) with AIC: -1947,068*

The results confirm our expectations. During the first period we observe that while modeling the error term variance using a GJR-GARCH(1,1) process improves the model, the preferred ARIMA model shows autoregressive lags for one period and moving average lags two trading days back. Thus, the model suggests that future returns are dependent on its own lagged return as well as lagged residuals. Furthermore, the superiority of the GJR-GARCH(1,1) suggests that allowing for asymmetric variances depending on the nature of news better captures volatility clustering.

When examining the results for the second sub period we observe entirely different results. All autoregressive behavior has vanished, where an ARIMA(0,0,0) is the preferred model, regardless of the modeling of the error term variance. Furthermore, the basic model is only improved by modeling the variance with a GARCH(1,1) process. Thus, in absence of extraordinary events (such as the one observed in April 2006) the error term variance does not seem to react asymmetrically to news. The conclusion of the results is that the sample now follows a random walk, meaning that the best forecast for today's return is the previous day's return. The market has thus become more efficient over time, which is expected due the higher liquidity and more active market participants.

6.4. Results and analysis from hypothesis 4

"There is no convenience yield by holding EUA spot contracts during the Kyoto-commitment period."

The most interesting issue is to see whether the results also hold for 2008, since no previous research has been conducted for this significant sample period. Looking at the results from hypothesis 1 and 3 we compare the results from convenience yields and ARIMA modeling. Firstly, since 2008 is the first period for which we can obtain Kyoto-commitment period spot prices we can investigate whether there is a significant convenience yields. We repeat our tests from hypothesis 1 using future and spot data from 2008-02-26 to 2008-08-12. The test period is dictated by the availability of spot data. Our hypothesis is formulated as follows:

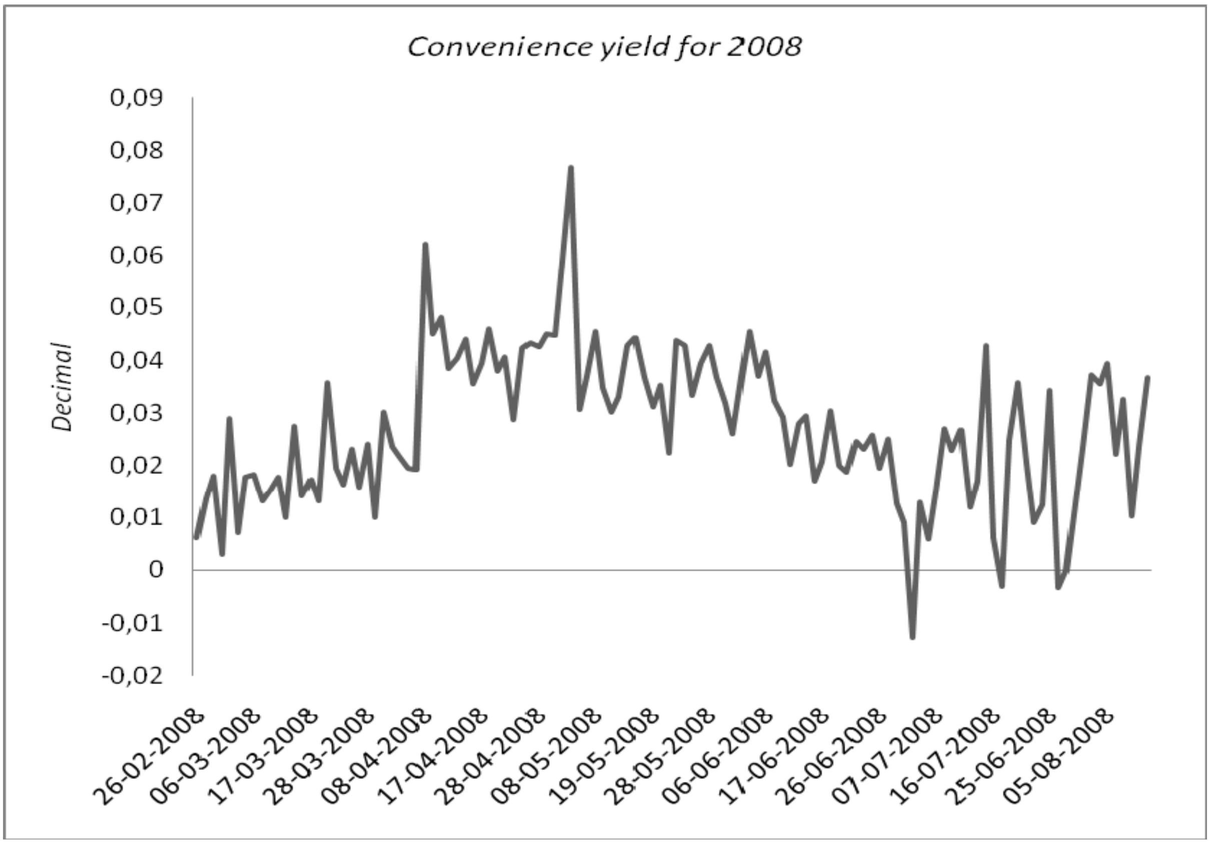
Kyoto commitment period

$H_0 : \delta = 0$ for $0.342 \le (T - t) \le 0.803$ years

where 0,803 corresponds to the number of years to maturity from the first observation (Febuary 26th, 2008) and 0,342 corresponds to August 12th , 2008.

When testing the hypothesis we could reject the null hypotheses of no significant convenience yield at the 5% level. Both the test statistics and the graph shown below indicate a positive convenience yield.

Figure 7



Although we obtained the same result during the first sub period within the pre-commitment period, we are surprised to find such a result during the Kyoto commitment period, in which the market has become vastly more efficient than during the initial trading years. The result also runs counter to the reasoning of Milunovich and Joyeux (2007) who state that there is no reasonable explanation for significant convenience yields over short periods of time. However, as stated during previous tests, we are assuming that the relation between spot and futures is explained by the cost-of-carry approach. Such an assumption may be invalid. As such, Hypothesis 4 does not hold.

6.5. Results and analysis from hypothesis 5

"The Kyoto-commitment period market follows a random walk behavior."

To test Hypothesis 5 we model the 2008 future prices applying ARIMA modeling. Assuming that the market has become more efficient during the 2008 months we expect that there is no significant autocorrelation in EUA future returns. When modeling the logged returns of EUA futures, using the same ARIMA modeling procedure as before, we find that our *a priori* assumptions are confirmed. As seen in the table below the most preferred model is an ARIMA(0,0,0) in all tests.

Table 8

Summary of ARIMA models

Preferred Model	**AIC**	**BIC**
ARIMA (0,0,0)	-757,7583	**-751,6586**
ARIMA (0,0,0) ARCH(1,1)	-755,8582	-746,7087
ARIMA (0,0,0) GARCH(1,1)	-759,4918	-747,2924

Furthermore, the lowest BIC value is obtained using standard ARIMA modeling, without any ARCH or GARCH modeling of the residual variance. These results suggest that the market has increased in efficiency. What is also noteworthy is that when running the 2008 test we find that when we combine ARIMA modeling with a GJR-GARCH process as the software cannot handle the default 1600 iterations. By lowering the iterations to 200 we obtain AIC and BIC values but regard these iterations as too few to be robust and thus exclude the testing of AIRMA with a GJR-GARCH process. We further motive our decision by the fact that we do not believe that taking asymmetric shifts in the error term variance into account will be relevant for this sample period, especially when taking the previous findings into consideration. We thus conclude that Hypothesis 5 holds.

7. Conclusions

From the initial introduction of emission rights in 2005, the market for emission rights has evolved from an immature and inefficient market to become more liquid, researched and increased in importance for market participants, as well as the public eye. As seen in this thesis, the relative immaturity of the EUA market has exhibited market anomalies not seen in any other market. The high irregularities during the pre-commitment period are largely due to the banking restrictions and excess supply of EUAs on the market. Although these factors have had huge affects on the market, these anomalies have now vanished and should not be a determinant factor in the future.

The test for convenience yields shows that although the full sample period shows significant negative convenience yields, the first sub-period show the opposite result, with significant positive convenience yields suggesting an advantage of holding spot EUAs. These irrationalities lack economic intuition which leads us to question of the appropriateness of the cost-of-carry approach. Evidence such as significant negative correlation between the future returns and the interest rates suggest that the model is not appropriate based on our pricing assumptions. We thus conclude that although the cost-of-carry approach may be appropriate for future pricing when the market matures, it does not apply during the volatile and immature pre-commitment period. However, the results from the 2008 spot and future tests show a similar result, which further casts doubt on the appropriateness of the cost-of-carry approach. These results are further strengthened by the findings of Milunovich and Joyeux (2007), where none of the future contracts tested was priced with the cost-of-carry approach. The switch from backwardation to contango is also evident in Trück et al. (2006), although the authors do not reject cost-of-carry approach.

When testing correlation with other asset classes we can conclude that although we observe significant correlations with several asset classes, the correlation is weak and lacks economic significance. The fact that the interest rate is negatively correlated with future returns, as well as opposite signs on equity indices, indicates that the EUA market is highly unaffected by movements in other markets. As such we propose that EUAs can be efficiently incorporated as diversification tool by investors. Given the fact that EUAs are becoming more liquid and more familiar to investors, we expect the use of these instruments to increase in importance as diversification devices.

When testing the autocorrelation in the EUA market, ARIMA modeling indicates that the market exhibit autoregressive behavior in the first lag. At the initial stage, the market also seems to react asymptotically to the nature of the shock suggesting modeling the future return with an AR(1)MA(2) using a GJR-GARCH(1,1) process. Towards the end of the pre-commitment period this phenomenon seems to have lessened and the data series follows a random walk with a GARCH(1,1) process, thus rendering the EUA market efficient. The 2008 tests further reveal an increase in efficiency where the best BIC values are obtained by modeling the returns using an ARIMA(0,0,0) without any modeling of the error term variance. Conclusively, we see that the increased market liquidity and entrance of external investors has had a monumental effect on the efficiency of the market.

7.1. Suggestions for future research

Many researchers have struggled with data when examining the EUA market. Since the market is still evolving the future will most likely lead to stabilization of price volatility and better fits between spot prices and derivatives based on the underlying spot. Thus, we propose that further research is done on the subject using more data for the Kyoto-commitment period and beyond. Furthermore, as the market develops new derivatives for hedging purposes, such as option futures, swaps etc, it is of great interest to examine how these prices are determined and evolve, using econometric and derivatives theory to disentangle the different dynamics. Finally, due to the questionable results of the cost-of-carry approach we propose that further research be conducted within this area, where testing other models, or including more data, may yield more robust results. Because of the growing importance of global environmental issues and the trend of internalizing worldwide externalities through the use of exchange traded instruments we believe that the carbon market is here to stay and will grow with exponential pace.

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http://en.exaa.at

Carbon Positive
http://www.carbonpositive.net

The Nordic Power Exchange Official Website
http://www.nordpool.com

The Bluenext Exchange (Europe's leading spot EUA exchange) http://www.bluenext.fr

Mondo Visione World Wide Exchange Intelligence
http://www.mondovisione.com

Point Carbon – Press Release, 5 March 2007
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9. Appendix

Appendix A:

Annex I Parties

Annex I countries (industrialized countries): Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom, United States of America

(40 countries and separately the European Union)

Annex II Parties

Annex II countries (developed countries which pay for costs of developing countries) Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States of America

(23 countries and separately the European Union; Turkey was removed from the annex II list in 2001 at its request to recognize its economy as a transition one.)

Appendix B:

Summary statistics for logarithmic future prices

Time period	**Observations**	**Variance**	**Skewness**	**Kurtosis**
2005-04-22 – 2007-12-31	690	0,0285027	0,0072322	2,948254
2005-04-22 – 2006-04-26	258	0,0231713	0,2624998	2,590044
2006-04-27 – 2007-12-31	432	0, 0219866	-0,337983	2,294492

Summary statistics for future return

Time period	**Observations**	**Variance**	**Skewness**	**Kurtosis**
2005-04-22 – 2007-12-31	689	0,0009082	-1,473214	19,25649
2005-04-22 – 2006-04-26	257	0,0011061	-3,349124	27,29774
2006-04-27 – 2007-12-31	432	0,0007924	0,3755129	9,18231

Summary statistics for logarithmic spot prices				
Time period	**Observations**	**Variance**	**Skewness**	**Kurtosis**
2005-06-24 – 2007-12-28	627	5,459165	-0,719203	1,858368
2005-04-22 – 2006-04-26	209	0,0112764	0,2752671	2,050139
2006-04-27 – 2007-12-28	418	5,093551	-0,1246736	1,392128

Summary statistics for spot return				
Time period	**Observations**	**Variance**	**Skewness**	**Kurtosis**
2005-04-22 – 2007-12-31	626	0,0067903	-0,442526	11,38295
2005-04-22 – 2006-04-26	208	0,0007633	-1,375309	9,265755
2006-04-27 – 2007-12-28	418	0,0096997	-0,2134445	8,273111

Appendix C:

First period for Dec 08 futures, i.e. 2005-04-25 (loss of first observation due to first difference) – 2006-04-26.

Summary of correlation between EUA future returns and major asset classes		
Index	**Asset Class**	**Correlation (%)**
DAX	German Equity Market	-4,10
FTSE	UK Equity Market	4,29
S&P500	US Equity Market	-1,99
S&P World Index	Global Equity Market	3,39
FTSE Europe Index	European Equity Market	1,58
Morgan Stanley Europe Energy Index	European Energy Equity Market	17,37**
Brent Crude Oil (€/barrel)	Oil prices	15,87*
Natural Gas-Henry Hub (€/MMBTU)	Gas prices	10,19
EURIBOR (1 year)	EU Interest rate	-13,86*
EURIBOR (1 week)	EU Interest rate	-3,36
LIBOR (3 months)	US Interest rate	-13,95*
Powernext Base Electricity (€/MWh)	Energy prices	5,63
Powernext Peak Electricity (€/MWh)	Energy prices	6,81

**Correlation is significance at the 5 % level.*
***Correlation is significance at the 1 % level.*

Second period for 08 futures, i.e. 2006-04-27 – 2007-12-31

Summary of correlation between EUA future returns and major asset classes		
Index	**Asset Class**	**Correlation (%)**
DAX	German Equity Market	2,12
FTSE	UK Equity Market	3,62
S&P500	US Equity Market	-3,41

S&P World Index	Global Equity Market	-0,01
FTSE Europe Index	European Equity Market	1,21
Morgan Stanley Europe Energy Index	European Energy Equity Market	10,61*
Brent Crude Oil (€/barrel)	Oil prices	13,46**
Natural Gas-Henry Hub (€/MMBTU)	Gas prices	6,05
EURIBOR (1 year)	EU Interest rate	-9,85*
EURIBOR (1 week)	EU Interest rate	0,98
LIBOR (3 months)	US Interest rate	-4,08
Powernext Base Electricity (€/MWh)	Energy prices	-2,42
Powernext Peak Electricity (€/MWh)	Energy prices	-1,80

**Correlation is significance at the 5 % level.*
***Correlation is significance at the 1 % level.*

First period for 08 futures, i.e. 2005-04-25 (loss of first observation due to first difference) – 2006-04-26

Summary of partial correlation between EUA future returns and major asset classes

Index	**Asset Class**	**Correlation (%)**
DAX	German Equity Market	-0,45
FTSE	UK Equity Market	3,60
S&P500	US Equity Market	-3,81
S&P World Index	Global Equity Market	1,97
FTSE Europe Index	European Equity Market	-5,64
Morgan Stanley Europe Energy Index	European Energy Equity Market	13,63*
Brent Crude Oil (€/barrel)	Oil prices	3,54
Natural Gas-Henry Hub (€/MMBTU)	Gas prices	3,65
EURIBOR (1 year)	EU Interest rate	-6,23
EURIBOR (1 week)	EU Interest rate	-4,23
LIBOR (3 months)	US Interest rate	-6,92
Powernext Base Electricity (€/MWh)	Energy prices	-1,32
Powernext Peak Electricity (€/MWh)	Energy prices	3,70

**Correlation is significance at the 5 % level.*

Second period for 08 futures, i.e. 2006-04-27 – 2007-12-31

Summary of partial correlation between EUA future returns and major asset classes

Index	**Asset Class**	**Correlation (%)**
DAX	German Equity Market	8,26
FTSE	UK Equity Market	7,91
S&P500	US Equity Market	-6,27
S&P World Index	Global Equity Market	5,64
FTSE Europe Index	European Equity Market	-12,26*
Morgan Stanley Europe Energy Index	European Energy Equity Market	9,63*
Brent Crude Oil (€/barrel)	Oil prices	5,83
Natural Gas-Henry Hub (€/MMBTU)	Gas prices	3,81
EURIBOR (1 year)	EU Interest rate	-10,09*
EURIBOR (1 week)	EU Interest rate	2,70
LIBOR (3 months)	US Interest rate	1,47
Powernext Base Electricity (€/MWh)	Energy prices	-4,75
Powernext Peak Electricity (€/MWh)	Energy prices	4,17

Appendix D:

Autocorrelation and partial autocorrelation

Correlogram of future return

Lag	AC	PAC	Q	Prob>Q
1*	0.1281	0.1281	11.347	0.0008
2	0,0464	0,0304	12,839	0,0016
3	0,0111	0,0011	12,924	0,0048
4	0,0395	0,0370	14,006	0,0073
5	-0,0033	-0,0132	14,014	0,0155
6	-0,1042	-0,1073	21,584	0,0014
7	0,0274	0,0555	22,11	0,0024
8	0,0179	0,0155	22,344	0,0043
9	-0,0134	-0,0212	22,46	0,0075
10	0,0204	0,0330	22,752	0,0117

**Correlation is significance at the 5 % level.*

Appendix E:

Whole period for 08 futures, i.e. 2005-04-25 (loose first observation due to first diff) – 2007-12-31

Summary of ARIMA models

ARIMA Model	Observations	AIC	BIC
ARIMA (0,0,0)	689	-2867.489	-2858.419
ARIMA (0,0,1)	689	-2876.078	-2862.472
ARIMA (0,0,2)	689	-2875.442	-2857.301
ARIMA (0,0,3)	689	-2873.444	-2850.768
ARIMA (1,0,0)	689	-2876.887	-2863.282
ARIMA (1,0,1)	689	-2875.564	-2857.423
ARIMA (1,0,2)	689	-2873.522	-2850.846
ARIMA (1,0,3)	689	-2871.522	-2844.311
ARIMA (2,0,0)	689	-2875.523	-2857.382
ARIMA (2,0,1)	689	-2873.559	-2850.883
ARIMA (2,0,2)	689	-2871.568	-2844.357
ARIMA (2,0,3)	689	-2869.715	-2837.968
ARIMA (3,0,0)	689	-2873.523	-2850.847
ARIMA (3,0,1)	689	-2876.340	-2849.128
ARIMA (3,0,2)	689	-2869.646	-2837.900
ARIMA (3,0,3)	689	-2872.809	-2836.527

Whole period for 08 futures, i.e. 2005-04-25 (loose first observation due to first diff) – 2007-12-31

Summary of ARIMA models using ARCH (1,1)

ARCH (1,1) Model	Observations	AIC	BIC
ARIMA (0,0,0)	689	-2977,041	-2963,436
ARIMA (0,0,1)	689	-2975,624	-2957,483
ARIMA (0,0,2)	689	-2979,248	-2956,483
ARIMA (0,0,3)	689	-2992,482	-2965,270
ARIMA (1,0,0)	689	-2974,627	-2956,486
ARIMA (1,0,1)	689	-2972,746	-2950,070
ARIMA (1,0,2)	689	-2995,523	-2968,312
ARIMA (1,0,3)	689	-2978,877	-2947,130
ARIMA (2,0,0)	689	-2973,117	-2950,441
ARIMA (2,0,1)	689	-2982,492	-2955,280
ARIMA (2,0,2)	689	-2983,454	-2951,707
ARIMA (2,0,3)	689	-2992,926	-2956,645
ARIMA (3,0,0)	689	-2987,812	-2960,601
ARIMA (3,0,1)	689	-2977,755	-2946,008
ARIMA (3,0,2)	689	-2993,372	-2957,090
ARIMA (3,0,3)	689	-2993,547	-2952,730

Whole period for 08 futures, i.e. 2005-04-25 (loose first observation due to first diff) – 2007-12-31

Summary of ARIMA models using GARCH (1,1)

GARCH (1,1) Model	Observations	AIC	BIC
ARIMA (0,0,0)	689	-3032.019	-3013.878
ARIMA (0,0,1)	689	-3039.443	-3016.767
ARIMA (0,0,2)	689	-3038.786	-3011.575
ARIMA (0,0,3)	689	-3041.833	-3010.086
ARIMA (1,0,0)	689	-3040.028	-3017.351
ARIMA (1,0,1)	689	-3038.034	-3010.823
ARIMA (1,0,2)	689	-3044.180	-3012.434
ARIMA (1,0,3)	689	-3043.139	-3006.857
ARIMA (2,0,0)	689	-3038.041	-3010.830
ARIMA (2,0,1)	689	-3043.790	-3012.043
ARIMA (2,0,2)	689	-3042.873	-3006.591
ARIMA (2,0,3)	689	-3040.945	-3000.128
ARIMA (3,0,0)	689	-3039.334	-3007.588
ARIMA (3,0,1)	689	-3042.013	-3005.731
ARIMA (3,0,2)	689	-3040.960	-3000.143
ARIMA (3,0,3)	689	-3045.945	-3000.592

Whole period for 08 futures, i.e. 2005-04-25 (loss of first observation due to first difference) – 2007-12-31

Summary of ARIMA models using GJR-GARCH (1,1)

GJR-GARCH (1,1) Model	Observations	AIC	BIC
ARIMA (0,0,0)	689	-3041.218	-3018.542
ARIMA (0,0,1)	689	-3048.759	-3021.547
ARIMA (0,0,2)	689	-3047.365	-3015.618
ARIMA (0,0,3)	689	-3049.674	-3013.392
ARIMA (1,0,0)	689	-3049.021	-3021.810
ARIMA (1,0,1)	689	-3047.041	-3015.294
ARIMA (1,0,2)	689	-3049.530	-3013.248
ARIMA (1,0,3)	689	-3048.346	-3007.529
ARIMA (2,0,0)	689	-3047.062	-3015.315
ARIMA (2,0,1)	689	-3052.123	-3015.841
ARIMA (2,0,2)	689	-3050.971	-3010.153
ARIMA (2,0,3)	689	-3054.131	-3008.779
ARIMA (3,0,0)	689	-3047.183	-3010.901
ARIMA (3,0,1)	689	-3052.293	-3011.476
ARIMA (3,0,2)	689	-3051.013	-3005.661

First period for 08 futures, i.e. 2005-04-25 (loss of first observation due to first difference) – 2006-04-26

Summary of ARIMA models

ARIMA Model	Observations	AIC	BIC
ARIMA (0,0,0)	257	-1017.048	-1009.950
ARIMA (0,0,1)	257	-1029.530	-1018.883
ARIMA (0,0,2)	257	-1028.657	-1014.461
ARIMA (0,0,3)	257	-1026.771	-1009.025
ARIMA (1,0,0)	257	-1030.729	-1020.082
ARIMA (1,0,1)	257	-1028.731	-1014.535
ARIMA (1,0,2)	257	-1027.388	-1009.643
ARIMA (1,0,3)	257	-1025.404	-1004.109
ARIMA (2,0,0)	257	-1028.731	-1014.534
ARIMA (2,0,1)	257	-1027.080	-1009.335
ARIMA (2,0,2)	257	-1025.392	-1004.098
ARIMA (2,0,3)	257	-1029.552	-1008.258
ARIMA (3,0,0)	257	-1027.097	-1009.352
ARIMA (3,0,1)	257	-1025.855	-1004.561
ARIMA (3,0,2)	257	-1030.503	-1009.209
ARIMA (3,0,3)	257	-1029.009	-1000.616

First period for 08 futures, i.e. 2005-04-25 (loss of first observation due to first difference) – 2006-04-26

Summary of ARIMA models using ARCH (1,1)

ARCH (1,1) Model	Observations	AIC	BIC
ARIMA (0,0,0)	257	-1093.050	-1082.403
ARIMA (0,0,1)	257	-1097.388	-1083.192
ARIMA (0,0,2)	257	-1118.287	-1100.542
ARIMA (0,0,3)	257	-1121.119	-1099.824
ARIMA (1,0,0)	257	-1105.973	-1091.776
ARIMA (1,0,1)	257	-1104.381	-1086.636
ARIMA (1,0,2)	257	-1107.235	-1085.941
ARIMA (1,0,3)	257	-1123.050	-1098.206
ARIMA (2,0,0)	257	-1105.526	-1087.781
ARIMA (2,0,1)	257	-1108.369	-1087.075
ARIMA (2,0,3)	257	-1125.263	-1096.870
ARIMA (3,0,0)	257	-1118.845	-1097.550
ARIMA (3,0,1)	257	-1106.972	-1082.128
ARIMA (3,0,2)	257	-1112.350	-1083.957
ARIMA (3,0,3)	257	-1130.090	-1098.148

First period for 08 futures, i.e. 2005-04-25 (loss of first observation due to first difference) – 2006-04-26

Summary of ARIMA models using GARCH (1,1)

GARCH (1,1) Model	Observations	AIC	BIC
ARIMA (0,0,0)	257	-1097.004	-1082.808
ARIMA (0,0,1)	257	-1100.462	-1082.717
ARIMA (0,0,2)	257	-1116.813	-1095.518
ARIMA (0,0,3)	257	-1119.383	-1094.539
ARIMA (1,0,0)	257	-1104.023	-1086.277
ARIMA (1,0,1)	257	-1102.214	-1080.919
ARIMA (1,0,2)	257	-1122.851	-1098.008
ARIMA (1,0,3)	257	-1115.312	-1086.919
ARIMA (2,0,0)	257	-1104.466	-1083.172
ARIMA (2,0,1)	257	-1118.220	-1093.377
ARIMA (3,0,0)	257	-1117.194	-1092.351
ARIMA (3,0,2)	257	-1110.489	-1078.547
ARIMA (3,0,3)	257	-1121.134	-1085.643

First period for 08 futures, i.e. 2005-04-25 (loss of first observation due to first difference) – 2006-04-26

Summary of ARIMA models using GJR-GARCH (1,1)

GJR-GARCH (1,1) Model	Observations	AIC	BIC
ARIMA (0,0,0)	257	-1106.469	-1088.723
ARIMA (0,0,1)	257	-1110.034	-1088.739
ARIMA (0,0,2)	257	-1124.522	-1099.679
ARIMA (0,0,3)	257	-1126.072	-1097.679
ARIMA (1,0,0)	257	-1114.939	-1093.645
ARIMA (1,0,1)	257	-1110.563	-1085.720
ARIMA (1,0,2)	257	-1130.952	-1102.560
ARIMA (1,0,3)	257	-1123.311	-1091.369
ARIMA (2,0,0)	257	-1114.774	-1089.930
ARIMA (2,0,1)	257	-1128.147	-1099.755
ARIMA (2,0,2)	257	-1129.241	-1097.300
ARIMA (2,0,3)	257	-1130.820	-1095.330
ARIMA (3,0,0)	257	-1124.624	-1096.231
ARIMA (3,0,1)	257	-1115.492	-1083.550
ARIMA (3,0,2)	257	-1127.416	-1091.926
ARIMA (3,0,3)	257	-1128.820	-1089.780

Second period for 08 futures, i.e. 2006-04-27 – 2007-12-31

Summary of ARIMA models

ARIMA Model	Observations	AIC	BIC
ARIMA (0,0,0)	432	-1855.711	-1847.575
ARIMA (0,0,1)	432	-1854.390	-1842.184
ARIMA (0,0,2)	432	-1854.761	-1838.487
ARIMA (0,0,3)	432	-1853.478	-1833.136
ARIMA (1,0,0)	432	-1854.295	-1842.089
ARIMA (1,0,1)	432	-1854.073	-1837.799
ARIMA (1,0,2)	432	-1853.984	-1833.642
ARIMA (1,0,3)	432	-1852.037	-1827.626
ARIMA (2,0,0)	432	-1854.705	-1838.431
ARIMA (2,0,1)	432	-1853.933	-1833.591
ARIMA (2,0,2)	432	-1854.258	-1829.848
ARIMA (2,0,3)	432	-1853.115	-1828.704
ARIMA (3,0,0)	432	-1853.660	-1833.318
ARIMA (3,0,1)	432	-1852.072	-1827.661
ARIMA (3,0,2)	432	-1852.523	-1824.044
ARIMA (3,0,3)	432	-1853.935	-1825.456

Second period for 08 futures, i.e. 2006-04-27 – 2007-12-31

Summary of ARIMA models using ARCH (1,1)

ARCH (1,1) Model	Observations	AIC	BIC
ARIMA (0,0,0)	432	-1903.776	-1891.571
ARIMA (0,0,1)	432	-1901.836	-1885.562
ARIMA (0,0,2)	432	-1902.430	-1882.088
ARIMA (0,0,3)	432	-1903.251	-1878.840
ARIMA (1,0,0)	432	-1901.821	-1885.547
ARIMA (1,0,1)	432	-1900.218	-1879.876
ARIMA (1,0,2)	432	-1901.429	-1877.019
ARIMA (1,0,3)	432	-1901.291	-1872.812
ARIMA (2,0,0)	432	-1902.771	-1882.429
ARIMA (2,0,1)	432	-1902.244	-1877.834
ARIMA (2,0,2)	432	-1904.830	-1876.351
ARIMA (2,0,3)	432	-1903.283	-1870.736
ARIMA (3,0,0)	432	-1904.213	-1879.803
ARIMA (3,0,1)	432	-1902.366	-1873.887
ARIMA (3,0,2)	432	-1903.872	-1871.324
ARIMA (3,0,3)	432	-1901.353	-1864.737

Second period for 08 futures, i.e. 2006-04-27 – 2007-12-31

Summary of ARIMA models using GARCH (1,1)

GARCH (1,1) Model	Observations	AIC	BIC
ARIMA (0,0,0)	432	-1952.764	-1936.490
ARIMA (0,0,1)	432	-1952.633	-1932.291
ARIMA (0,0,2)	432	-1952.478	-1928.067
ARIMA (0,0,3)	432	-1951.917	-1923.438
ARIMA (1,0,0)	432	-1952.332	-1931.990
ARIMA (1,0,1)	432	-1951.290	-1926.879
ARIMA (1,0,2)	432	-1951.140	-1922.661
ARIMA (1,0,3)	432	-1951.351	-1918.804
ARIMA (2,0,0)	432	-1953.103	-1928.692
ARIMA (2,0,1)	432	-1951.520	-1923.041
ARIMA (2,0,2)	432	-1952.393	-1919.845
ARIMA (2,0,3)	432	-1953.947	-1917.331
ARIMA (3,0,0)	432	-1951.911	-1923.432
ARIMA (3,0,1)	432	-1951.698	-1919.151
ARIMA (3,0,2)	432	-1953.635	-1917.019

Second period for 08 futures, i.e. 2006-04-27 – 2007-12-31

Summary of ARIMA models using GJR-GARCH (1,1)

GJR-GARCH (1,1) Model	Observations	AIC	BIC
ARIMA (0,0,0)	432	-1952.079	-1931.736
ARIMA (0,0,1)	432	-1952.092	-1927.682
ARIMA (0,0,2)	432	-1952.028	-1923.549
ARIMA (0,0,3)	432	-1951.517	-1918.969
ARIMA (1,0,0)	432	-1951.755	-1927.344
ARIMA (1,0,1)	432	-1950.793	-1922.314
ARIMA (1,0,2)	432	-1950.650	-1918.103
ARIMA (1,0,3)	432	-1951.272	-1914.656
ARIMA (2,0,0)	432	-1952.732	-1924.253
ARIMA (2,0,1)	432	-1951.106	-1918.559
ARIMA (2,0,2)	432	-1950.275	-1913.660
ARIMA (2,0,3)	432	-1953.552	-1912.868
ARIMA (3,0,0)	432	-1951.507	-1918.960
ARIMA (3,0,1)	432	-1951.678	-1915.062
ARIMA (3,0,2)	432	-1948.400	-1907.716
ARIMA (3,0,3)	432	-1948.010	-1903.257

Appendix F:

08-Future contracts during Kyoto-commitment period (i.e. 2008-01-02 – 2008-08-12)

Summary of ARIMA models

ARIMA Model	Observations	AIC	BIC
ARIMA (0,0,0)	156	-757.7583	-751.6586
ARIMA (0,0,1)	156	-758.2769	-749.1274
ARIMA (0,0,2)	156	-757.0832	-744.8837
ARIMA (0,0,3)	156	-755.4522	-740.203
ARIMA (1,0,0)	156	-757.9693	-748.8197
ARIMA (1,0,1)	156	-757.9129	-745.7134
ARIMA (1,0,2)	156	-755.9184	-740.6691
ARIMA (1,0,3)	156	-753.0864	-734.7873
ARIMA (2,0,0)	156	-756.5784	-744.379
ARIMA (2,0,1)	156	-755.9194	-740.6701
ARIMA (2,0,2)	156	-755.0034	-736.7042
ARIMA (3,0,0)	156	-754.6919	-739.4426
ARIMA (3,0,1)	156	-754.1757	-735.8766
ARIMA (3,0,2)	156	-752.0298	-730.6808
ARIMA (3,0,3)	156	-758.1471	-733.7483

08-Future contracts during Kyoto-commitment period (i.e. 2008-01-02 – 2008-08-12)

Summary of ARIMA models using ARCH(1,1)

ARIMA Model	Observations	AIC	BIC
ARIMA (0,0,0)	156	-755.8582	-746.7087
ARIMA (0,0,1)	156	-756.3521	-744.1527

ARIMA (0,0,2)	156	-755.1428	-739.8935
ARIMA (0,0,3)	156	-753.5188	-735.2197
ARIMA (1,0,0)	156	-756.0306	-743.8312
ARIMA (1,0,1)	156	-755.9909	-740.7416
ARIMA (1,0,2)	156	-753.9918	-735.6927
ARIMA (1,0,3)	156	-752.1774	-730.8284
ARIMA (2,0,0)	156	-754.6382	-739.3889
ARIMA (2,0,1)	156	-753.992	-735.6929
ARIMA (3,0,0)	156	-752.7447	-734.4456
ARIMA (3,0,1)	156	-753.6917	-732.3427
ARIMA (3,0,2)	156	-750.1338	-725.7349
ARIMA (3,0,3)	156	-751.7014	-724.2527

08-Future contracts during Kyoto-commitment period (i.e. 2008-01-02 – 2008-08-12)

Summary of ARIMA models using GARCH(1,1)

ARIMA Model	**Observations**	**AIC**	**BIC**
ARIMA (0,0,0)	156	-759.4918	-747.2924
ARIMA (0,0,1)	156	-758.6782	-743.4289
ARIMA (0,0,2)	156	-758.7838	-740.4846
ARIMA (0,0,3)	156	-757.2534	-735.9044
ARIMA (1,0,0)	156	-758.4123	-743.163
ARIMA (1,0,1)	156	-759.1387	-740.8396
ARIMA (1,0,2)	156	-757.5439	-736.1949
ARIMA (2,0,0)	156	-757.7086	-739.4094
ARIMA (2,0,1)	156	-757.6271	-736.2782
ARIMA (2,0,3)	156	-755.0793	-727.6306
ARIMA (3,0,0)	156	-756.3321	-734.9831
ARIMA (3,0,1)	156	-755.9525	-731.5537
ARIMA (3,0,3)	156	-764.6939	-734.1954

Appendix G:

Graph 1

Plot of EUA future residuals