LAPPEENRANTA UNIVERSITY OF TECHNOLOGY

School of Business

FINANCE

Olli Hämäläinen

Commodity Future Price Premiums – Case EU ETS

Examiners: Professor Eero Pätäri

Associate Professor Kashif Saleem

ABSTRACT

Author:	Olli Hämäläinen
Tittle:	Commodity Future Price Premiums – Case EU ETS
Faculty:	Lappeenranta School of Business
Major:	Finance
Year:	2014
Examiners:	Professor Eero Pätäri
	Associate Professor Kashif Saleem
Master’s Thesis	LUT School of Business
	61 pages, 12 figures, 20 equations, 12 tables, 2 appendixes
Key words	future price premiums, emission allowances

The purpose of this thesis was to study commodity future price premiums and their nature on emission allowance markets. The EUA spot and future contracts traded on the secondary market during EU ETS Phase 2 and Phase 3 were selected for empirical testing.

The cointegration of spot and future prices was examined with Johansen cointegration methodology. Daily interest rates with a similar tenor to the future contract maturity were used in the cost-of-carry model to calculate the theoretical future prices and to estimate the deviation from the fair value of future contracts, assumed to be explained by the convenience yield. The time-varying dependence of the convenience yield was studied by regression testing the correlation between convenience yield and the time to maturity of the future contract.

The results indicated cointegration between spot and future prices, albeit depending on assumptions on linear trend and intercept in cointegration vector Dec-14 and Dec-15 contracts. The convenience yield correlates positively with the time-to-maturity of the future contract during Phase 2, but negatively during Phase 3. The convenience yield featured positive correlation with spot price volatility and negative correlation with future price volatility during both Phases 2 and 3.

TIIVISTELMÄ

Tekijä:	Olli Hämäläinen
Aihe:	Hyödykefutuurien hintapreemiot – Case EU ETS
Laitos:	Kauppatieteellinen tiedekunta
Pääaine:	Rahoitus
Vuosi:	2014
Tarkastajat:	Professori Eero Pätäri
	Tutkija professori Kashif Saleem
Pro Gradu	LUT School of Business
	61 sivua, 12 kuviota, 20 kaavaa, 12 taulukkoa, 2 liitettä
Avainsanat	futuurien hintapreemiot, päästöoikeudet

Tutkielman tavoitteena oli tutkia päästöoikeusfutuurien hintapreemioita ja niihin vaikuttavia tekijöitä. Tutkimuksen aineistoksi valittiin EU ETS sekundäärimarkkinoilla 2. vaiheen ja 3. vaiheen aikana vaihdetut EUA spot- ja futuurisopimukset.

Spot- ja futuurisopimusten hintojen yhteisintegraatiota tutkittiin Johansenin menetelmällä. Teoreettisten futuurisopimusten hintojen sekä niiden ja markkinahintojen hintaeron laskemiseksi käytettiin päivittäin noteerattuja korkoja futuurisopimuksia vastaavalla juoksuajalla. Hintaeron oletettiin selittyvän mukavuustuotolla. Mukavuustuoton aikariippuvuutta tutkittiin regressiotestaamalla sen ja ja futuurisopimuksen jäljellä olevan juoksuajan välistä korrelaatiota.

Tulokset osoittavat spot- ja futuurihintojen olevan yhteisintegroituneita, vaikkakin tulosten validius riippuu oletuksista lineaarisesta trendistä ja vakiotermistä yhteisintegraatiovektorissa. Mukavuustuotto korreloi positiivisesti futuurisopimuksen jäljellä olevan juoksuajan kanssa toisen vaiheen aikana, mutta negatiivisesti kolmannen vaiheen aikana. Mukavuustuotto korreloi positiivisesti spothinnan volatiliteetin ja negatiivisesti futuurihintojen volatiliteetin kanssa molempien vaiheiden 2 ja 3 aikana.

ACKNOWLEDGEMENTS

Having the opportunity to study for two separate M.Sc. degrees at Lappeenranta University of Technology has been an inspiring and career enhancing experience. I would like to thank Professor Eero Pätäri and Associate Professor Kashif Saleem for the valuable guidance on my thesis. The support from my wife has been invaluable and precious, as well as seeing our daughter smile and grow every day.

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS

ACRONYMS

CO2	Carbon dioxide
CER	Certified Emission Reduction
CDM	Clean Development Mechanism
ECB	European Central Bank
EU ETS	European Union Emission Trading System
EUA	European Union Allowance
EEX	European Energy Exchange
GHG	Greenhouse Gas
ICE	Intercontinental Exchange
Phase 1	The first EU ETS trading and compliance period
Phase 2	The second EU ETS trading and compliance period
Phase 3	The third EU ETS trading and compliance period

1. INTRODUCTION

1.1 Background

In spite of the vivid debate on climate change, contributing factors, appropriate policies and proper regulatory response it can be claimed that regulatory actions and targets regarding desired emission levels will lead to new economic opportunities and effects on businesses. Several emission trading schemes have been implemented and they have faced relatively significant changes during their short time of existence, especially when compared with more mature commodity markets. The European greenhouse gas emissions trading system, the European Union Emission Trading System (EU ETS), was launched in 2005 as a response to the emission targets committed in Kyoto protocol and the subsequent EU directive 2003/87/EC (European Union, 2003). The objective of the EU ETS is to reduce greenhouse gas emissions by 2020 to a level that represents 21% reduction to 2005 levels. The EU ETS is a cap-and-trade emission reduction system covering over 11,000 power stations and manufacturing sites across all EU member states, Iceland, Liechtenstein and Norway. EU ETS covers approximately 45% of the total greenhouse gas emissions from the covered countries (European Union Publications Office, 2013). Aviation industry has been recently added into the scope of the EU ETS via the introduction of directive 2008/101/EC (European Union, 2008).

Similar to the price of electricity and energy commodities, the market price of emission allowances has been historically relatively volatile. Risk managers of companies that are liable to offset their carbon emissions by surrendering emission permits are interested in managing the price risk. The price of carbon contributes to the overall cost of companies' production and increases uncertainty regarding the cost base due to the variable nature of the price. Secondly, various types of carbon emission offset projects and investments in abatement technologies typically rely on the reduction of carbon emissions and the ability to sell the surplus of allocated allowances or new allowances created to other liable companies. EU ETS has been expected to push for market based reduction of carbon emissions and incentivize companies to invest in low-carbon intensive technologies, thus the uncertainty on allowance price may hinder investor confidence and willingness to bank on the economic benefits. In addition to the main market participants, speculators and traders are interested in the behavior of the spot and future prices. Understanding the market and behavior and any potential pricing inefficiencies may provide arbitrage opportunities but also improve the ability to manage risks in a better manner. This thesis will examine the relationship between CO2 allowance spot and future prices to contribute to the ongoing debate regarding market efficiency. Market based mechanisms are claimed to support the adaption of cleaner energy technologies, thus this thesis also supports and aligns with the green energy and technology area of focus pinpointed in the strategy of Lappeenranta University of Technology. Another motivation is to increase the understanding of the existence of potential future pricing premiums and convenience yields in the EU ETS and discus some explanatory factors of which some are potentially unique to emission allowance markets.

A number of academic studies have been conducted on exchange traded emission allowances, primarily in the context of the European Union Emissions Trading System (EU ETS) and Clean Development Mechanism (CDM). This thesis will provide some further evidence regarding the features of future prices especially during the second (Phase 2) and third (Phase 3) EU ETS compliance and trading periods on the secondary European Emission Allowance (EUA) markets. Secondly, it raises new research questions for future research purposes in emerging carbon allowance markets such as California ETS.

1.2 Objectives and research questions

The intangible nature of the emissions units, dependency on supporting legislation and regulatory uncertainty motivate market participants to manage price risk. In addition to emitters, the value of carbon is often vital for emission reduction projects to be economically viable. Any uncertainty on the price of carbon may increase the perceived risk of such projects. Furthermore, these factors may also reveal opportunities for speculation, arbitrage and proprietary trading strategies. Common interest shared by all market participants is the understanding of future pricing premiums and characteristics of the market, hence inspiring the topic of this thesis.

The purpose of this thesis is to explore the existing theories on commodity and emission allowance future price premiums, research and test the cointegration between spot and future prices, test the sensitivity of future price premiums in the EU ETS and explore potential explanatory factors. The main research question is divided into the following sub-questions:

1. What previous studies on emission allowance risk or price premiums have been conducted and what conclusions have been made?
2. Are emission allowance spot and future prices cointegrated?
3. Does emission future pricing include a premium i.e. does the observed market pricing systematically deviate from the theoretical cost-of-carry pricing model?
4. What are the potential explanatory factors explaining the quantum and variability of the future price premium?

As emission allowances differ from traditional commodities such as metals and oil, the intuition is that the pricing of future contracts should reflect the uncertainty rising from regulatory and political risks. The emission allowances and their value would not exist as such without policymakers actions. On the other hand, the spot and future prices should reflect the same information and demonstrate similar price movements in general. The common expectation is that the spot and future prices should reflect similar price movements at least in long term, although short-term deviations from this interrelation are possible. The findings from the literature regarding the validity of cost-of-carry model on CO2 allowances is to some extent controversial and will be explored further to address the first research question. The positive conclusions support the idea of cointegration between spot and future prices with some restrictions, hence the cost-of-carry model is argued to be valid for intra-phase contracts. The cointegration tests, conducted after unit root test, will address the second research question.

The intuition on the potential existence of future price premiums is based on the unordinary nature of emission allowances as commodities. This premium may indicate different market participants' desire to hedge against the impact of political or regulatory changes on prices, albeit this can increase the pressure on pricing on both directions. Political intents are typically speculated and communicated in public prior to the final legislative change, thus it may be theorized that some of that information may be reflected in future pricing with asymmetric interpretations of the outcome.

It can be argued that the holder of the emission allowance carries the regulatory risk in case the whole scheme was to be repealed and the intangible emission permit was to become worthless. Regulatory changes and different rules for each EU ETS phase may have resulted in fundamental shifts in future pricing. Different views on commodity future price premiums are discussed in the theory section. The deviation from the theoretical cost-of-carry price is assumed to be explained by convenience yield. The convenience yield is regression tested with spot and future price and their volatilities. These tests are expected to provide answers for the fourth research question regarding the factors affecting the future price premium.

1.3 Limitations

Due to the relatively short history and existence of the emission allowance markets especially when compared to more traditional commodities, the data is limited to the life span of the EU ETS covering the EUA spot and future prices traded on secondary market during Phase 2 and Phase 3. The relatively modest daily trading volumes and potential seasonality of the volume reduce the testing power. The convenience yield regression tests with spot price, future price and their volatilities are especially impacted by this. The EU ETS rules and unit allocation principles on primary market have been changed between compliance periods hence the pilot Phase 1 is excluded from this analysis. Previous research has primarily focused on Phase 2 of the EU ETS whereas this thesis mainly focuses on both Phase 2 and Phase 3.

The future and spot prices are expected to be cointegrated as indicated by previous studies and discussed in the literature review. The cointegration and interrelation between spot and future prices is expected to reflect similar dependency and reaction to the same information affecting the EU ETS pricing. The availability of inventory data constraint analysis on the relationship between inventory levels and convenience yield, hence the analysis on this relationship is excluded from this study.

1.4 Structure of this thesis

In Chapter 2 we introduce the economic theory behind emission pricing and explore different market mechanisms and implementations of existing emission trading schemes in order to familiarize the reader with such schemes. In Chapter 3 we discuss commodity future pricing theories and present the results of the studies on carbon emission allowance future pricing premiums regarding EU ETS. The state of literature regarding emission allowance price co-integration and validity of cost-of-carry model are presented in this chapter. We also briefly discuss the concept of price premiums and different results regarding market efficiency and convenience yield. As the future contracts are used in corporate risk management we discuss the rationale for companies to hedge. In Chapter 4 we present the methodologies applied in this thesis. In Chapter 5 we discuss the data used and in Chapter 6 we present the results for each of the tests and analysis performed. We finalize the thesis in conclusions in Chapter 7.

2. EMISSION ALLOWANCE MARKETS

2.1 Economic theory

From economic theory point of view, emissions and pollution can be considered as *negative externalities* imposing costs to third parties that are not included as a factor of production and fully reflected in the total cost-of-production. In the context of air-pollution, a classic example of negative externalities is acid rain caused by of emissions of sulfur dioxide and nitrogen oxide. This example is particularly straightforward, as acid rain caused by a byproduct with no direct cost to the originator has an impact to a third party. These impacts can be quantified and expressed as reduced agricultural productivity or additional food production costs, among other adverse effects such as health issues with long term impacts (Pindyck, 2011).

To some extent the negative externalities can be considered as property right issues. As emission related negative externalities violate private property rights, the involuntary transactions (e.g. unwanted acid rain fallout on landowner’s property) do not comply with the underlying principles of a free market. Controversial views exist on whether the originators of the externalities should be penalized and controlled individually or collectively through a market mechanism set by policymakers.

The theoretical rationale for pricing emissions is based on the assumption that without a policy instrument that sets a price on emissions there would be no direct production cost incurred by the producer, and in case of air pollutants, no signal indicating the increasing scarcity value of atmosphere as a sink to absorb these emissions. The market based approaches are supported by claims that they will empower market participants to find out the most cost effective ways to reduce emissions without excessive governmental intervention (Ellerman, 2010).

2.2 Emission allowance market mechanisms

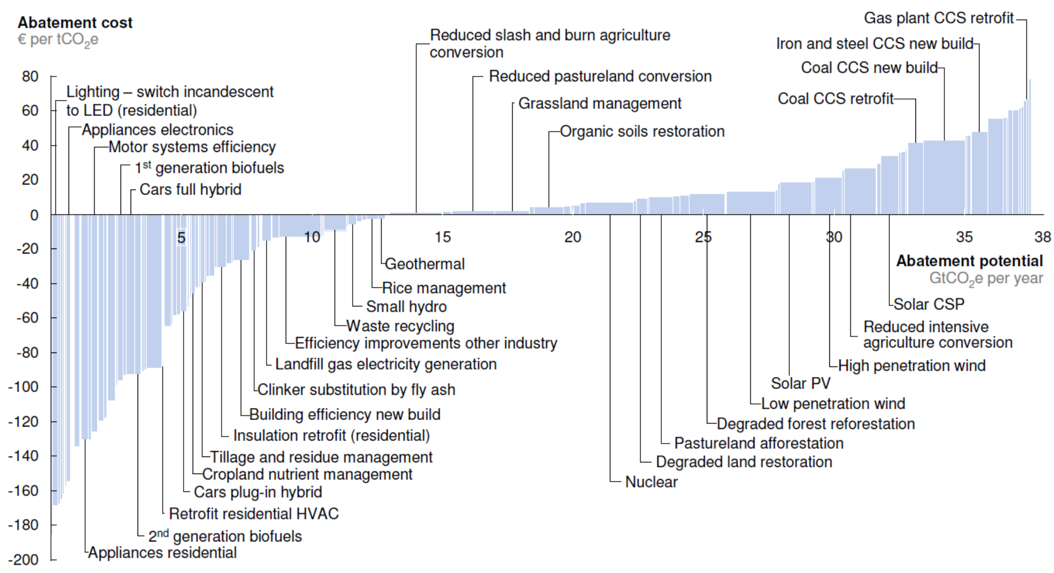
Emissions reduction and pricing schemes can be operated based on two different mechanisms. The first type of mechanism is based on a common cost on emissions, typically a tax that is attributed to emissions within a predetermined scope of emitters and with a constant unit price. The mechanism is supported by claims that the costs would be attributed to the originator and all parties would be treated equally due to the constant price. These types of schemes have been criticized as they do not incentivize market participants to find the most cost efficient way to reduce emissions, because they assume a constant cost to emitters with different cost bases and as there is no clearly indicated intent or limit of maximum emissions allowed (Goulder and Schein, 2013).

The second type of the mechanisms is a market based emission trading scheme which is typically based on cap-and-trade principles. Dales was among the first researches to propose a market based emission trading system back in 1969 (Dales, 2002). In cap-and-trade schemes, the regulator sets an emission cap and emitters are required to offset each ton of emissions by surrendering an emission allowance. Typically a limited amount of emission allowances are allocated by regulator for free. If the emitter needs more permits to offset emissions, they can buy more credits via spot or future markets from another party who is able to cut emissions with better economic outcome (Goulder and Schein, 2013). The cap-and-trade solution is criticized as the allocation of free permits is seen unjustifiable or inefficient. Furthermore, different cap-and-trade schemes operate with different instruments and linkages between schemes are limited or non-existent.

Emission trading schemes have an impact on multitude of other markets where GHG emissions are produced and which are covered by the emission reduction scheme. Electricity generators incur cost for their CO2 emissions, therefore this cost will increase the marginal cost of electricity and will increase pressure on electricity price. Various alternatives can be used to directly reduce emissions, improve efficiency or produce the same product or service in a completely different way in order to avoid some of the CO2 costs included in the marginal production costs (Harrison et al, 2005).

In an efficient market, the theory supporting the adaptation of different abatement options is that the price of allowance equals to the marginal cost of the lowest cost available alternative (Bloch, 2010). These abatement alternatives were categorized by Niemeyer as *Alternative Fuels* (e.g. switching diesel to gas), *Alternative Technologies* (e.g. geothermal replacing coal) and *Scrubbing Emissions (*e.g. advanced exhaust filtering technologies*)* (Chao & Wilson, 1993).

Figure 1. Global GHG abatement cost curve (McKinsey&Company, 2010)



Naturally, each of the alternatives has different costs and abatement potential on volumetric basis. McKinsey & Company have formulated indicative cost estimates and volumetric abatement potentials for different abatement approaches (Figure 1). Although the estimated costs are indicative, the abatement cost curve provides relative guidance when different alternatives are compared.

The alternatives and the associated abatement cost costs (euros per tCO_2-e) on the right hand side of the curve, such as for wind generators, can be interpreted as additional production costs compared with cheaper fossil fuel based alternatives (McKinsey & Company, 2010).

As mentioned earlier, GHG abatement investments typically rely on the benefit of fewer allowances required to be surrendered or the ability to create and sell tradable surplus allowances. According to Chao and Wilson the amount of investments in scrubbers depends on the perceived uncertainty and risk on allowance prices in the future. When uncertainty is considered high, the less viable these investments are considered (Chao and Wilson, 1993).

2.3 GHG allowance trading schemes worldwide

At the time of writing this study the following Emission Trading Schemes discussed by Talberg and Swoboda were operational: EU ETS, California cap-and-trade, Quebec cap-and trade, Swiss ETS, NZ ETS, Kazakhstan ETS and regional North-American emission reduction schemes (Talberg and Swoboda, 2013). It must be noted that the floating price ETS planned to start in Australia in 2015 is currently going through legislative changes and is unlikely to proceed in the originally planned manner. As this study focuses on spot and future contracts traded on EU ETS, we specifically discuss the market dynamics of that scheme later and introduce a selection of the other operational schemes briefly here.

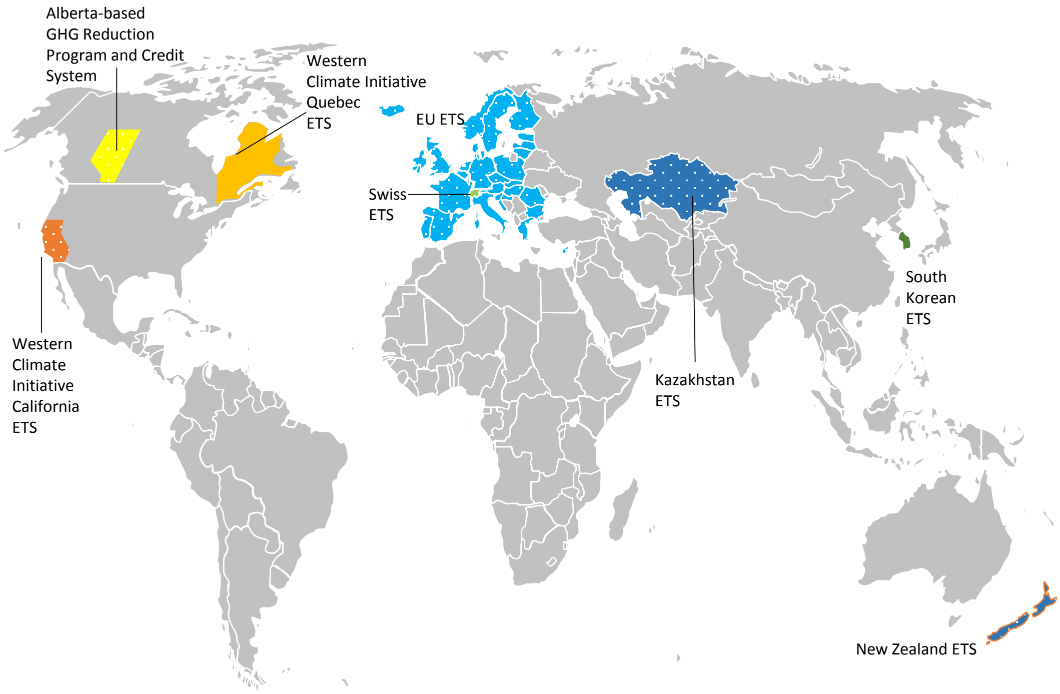
New Zealand ETS was commissioned in 2008 and currently covers forestry, waste management and energy sectors. The liable companies are required to surrender emission allowances, while eligible offset projects can create and sell allowances (NZ Ministry for the Environment, 2014). The NZ ETS can be described as a hybrid ETS as it features both emission tax and cap-and-trade properties. There is no common cap on emissions, thus the amount of emissions is theoretically unlimited. In addition, some non-market based reliefs have been created, such as the ability to buy allowances from the government for a fixed price and only 50% emission offsetting required from certain industry participants (NZ Ministry for the Environment, 2014).

Talberg and Swoboda have listed a number of North American GHG reduction schemes under the Westen Climate Initiative (WCI). California Cap-and-Trade ETS was launched in 2013 aiming to reduce California's GHG emissions to 1990 levels by 2020 (Walsh, 2013). The annual reduction in the emissions cap is set to 3 per cent after 2014 until 2020. Similar to NZ ETS the scheme gradually increases the sectors covered. Only electricity utilities and manufacturing are included in the first phase, with transportation and distribution of fossil fuels to be included from 2015. As a particular feature the regulator has set a price ceiling for the allowance prices. The base unit in the scheme is California Carbon Allowances (CCA) (Talberg and Swoboda, 2013). Quebec ETS, similar to California ETS, is closely related to California ETS due to linkage between these two systems effective early 2014 (Air Resource Board, 2014). A finding from the integration of these two schemes is that the schemes to be linked must be harmonized prior to linking and accepting allowances to be exchanged and cross-used between the schemes. The harmonization covers not only the industries covered, but also ensures offset projects eligible to create certificates operate on the same basis and result in similar offset GHG volumes.

Switzerland launched its own dedicated Swiss ETS in 2008 at the same time with a carbon tax system. At first medium sized companies had the option to either pay a carbon tax or become liable under the ETS. Since 2013 large companies have been liable under the ETS with no alternatives (Talberg and Swoboda, 2013). Kazakhstan is piloting a national cap-and-trade based ETS that was legislated in 2013.

The graphical summary of worldwide ETS systems in place is illustrated in Figure 2 which is based on the review and study conducted by Talberg and Swoboda.

Figure 2. Emission Trading Schemes (Talberg and Swoboda, 2013)



2.4 General market dynamics of EU ETS

The market efficiency of EU ETS and factors affecting pricing has been covered by a number of studies. According to Daskalakis the market efficiency has improved, indicating maturing market especially when compared to the early period of Phase 2 between 2008 and 2009. Daskalakis applied three technical trading and analysis strategies against two benchmark strategies to reveal existence of any predictability in pricing of four future contracts. The efficiency of these strategies in terms of risk-adjusted returns, however, decreased between 2009 and 2010 indicating improvement in market efficiency (Daskalakis, 2013)

The emission allowance prices can be considered as an input to liable firm’s production costs as the emissions are typically a function of the production level (e.g. coal fired electricity generation). The EU ETS allowance prices have been affected by the level of industrial productivity, changes in energy prices, investments in renewable energy and stockpiling of permits. (Talberg and Swoboda, 2013). Utility companies optimize their production based on fuel costs and associated emission costs.

According to Betz the key factors influencing the price volatility during the early days of EU ETS can be categorized into immaturity of the market, general price driving factors, supply side factors and demand side factors. Political decisions are crucial as they may affect future industries covered by the scheme, potential linkages between national schemes as well as banking and borrowing restrictions between different phases of EU ETS. Betz has also recognized the influence of fuel prices, abatement options, weather and economic growth as drivers for price volatility (Betz, 2006).

Alberola et al. have found EU ETS allowance prices to demonstrate significant dependency on energy prices and ambient temperatures, especially unanticipated temperature variations (Alberola et al, 2008). Of these the ambient temperatures have an impact on the demand side due to increased heating or cooling preferences and subsequent changes in volumes. Aatola et al. found strong relationship between German electricity prices, natural gas price and coal price with the EUA prices (Aatola et al. 2013). Chevallier concluded that carbon market is not strongly connected to macroeconomic variables, but rather correlates with energy commodities and power producers' fuel-switching decisions (Chevallier, 2009).

Benz and Trück identified the need to distinct separate factors influencing the spot price dynamics and price movements in EU ETS. The key drivers identified were policy and regulatory issues, argued to result in mean-reversion in the long-run, and market fundamentals influencing supply and demand causing short-term volatility and price shocks (Benz and Trück, 2006). When the integration between EU ETS and CDM instruments were studied by Mizrach, it was concluded that the political and regulatory uncertainties have prevented the price of these two instruments to converge (Mizrach, 2011). This conclusion was later extended by Nazifi who concluded that the uncertainty on CER and access to the use of CER instruments explain significant portion of the price difference (Nazifi, 2013).

3. THEORETICAL FRAMEWORK

3.1 Corporate risk management and hedging

The classic theories on the irrelevance of financial policies proposed by Modigliani and Miller suggest that that the performance of a company does not depend on its financing structure if there are no taxes, information is symmetric and no financial distress costs or transaction fees exist. Their propositions are also based on a prerequisite that investors would be able to diversify risks within their portfolios (Modigliani and Miller, 1958).

Hull suggests that in an ideal world companies' would best serve their shareholders' interests by not hedging non-systematic risks. According to Hull this theory is rarely followed. The deviation is caused by managerial risk aversion, desire for earnings predictability, shareholder preferences and real life constraints such as bankruptcy costs and regulatory requirements (Hull, 2012).

Modigliani's theorem relies on the assumption that investors are well diversified therefore the exposure to a single company's poor performance is offset by the performance of other companies in the portfolio. Companies with well diversified ownership structure are more likely to not hedge than companies with less diversified ownership structures (Nance et al. 1993). Shareholders with more concentrated and less diversified portfolios may be less willing to accept risks that could be mitigated with more diversified portfolios.

Managerial risk aversion is influenced by individual performance objectives and incentives. Alderson and Betker have found evidence that a company's net debt is negatively correlated with their managers' exposure to changes in the stock price and common stock based incentives, even if the company did not have long-term debt (Alderson and Betker, 2012). Managers' compensation is dependent on their employer's performance and it cannot be diversified as such.

Predictability of earnings may support more generous and sustainable dividend policies. Firms with less liquid assets and higher dividends have been found to be more likely to use hedging instruments (Nance et al. 1993). Firms with lower credit ratings are found to use more financial derivatives for hedging purposes (Wall and Pringle, 1989). Being able to pay out dividends consistently may require companies to secure and lock-in their cash flows to avoid liquidity constraints. Secondly, low credit rated companies with less buffers against short term cash flow fluctuations may seek to increase predictability by using hedging instruments.

3.2 Theories on future market pricing

Future markets can be categorized into *financial futures markets* (e.g. stock futures) and *commodity futures markets* (e.g. oil futures). According to Fama and French the valuation and pricing of commodity future contracts can be approached from two distinctive points of view and explained by using two different conceptual models. The first group of models suggests the pricing of future contracts to be based on the concept of a risk premium whereas the second group of models link future pricing with the cost and convenience of holding inventories (Fama and French, 1987).

The risk premium hypothesis and theories assume that the future price is equal to expected future spot value plus a risk premium. Keynes described future contracts as instruments to hedge against price volatility and to be primarily used to secure cash flows at the time the underlying asset is expected to be sold in the future. According to Keynes this certainty on the settlement price would imply a cost to the seller – coined as the hedger by Keynes. Keynes reasoned that the risk of spot price volatility is transferred to the buyer who is seeking for a return expressed as the difference between the exercise price and spot price at maturity. Keynes argued that the hedger has to pay for this risk transfer expressed as risk premium and which equals to the profit and compensation for carrying the risk provided to the speculator (Keynes, 1930; Trück et al, 2012). It must be noted that Keynes formulated these theories before the era and rise of electronic trading.

Keynes claimed commodity markets to be in state of *normal backwardation* where the price of a future contract is less than the expected spot price at maturity. Keynes assumed the speculators to go net long only when the futures prices are expected to rise. Later Hicks suggested that in some occasions speculators are net long and expect the price of forward or future contracts to decline (Hicks, 1939; Wolfe, 1968). This phenomenon called *normal contango* is observable when the future contracts trade above the expected spot price and decline when approaching maturity.

Both theories regarding normal backwardation and contango have faced both sparse critique and acclaims from numerous academics since their inception. Trück et al have summarized the different market states discussed by Pindyck and Hull being *backwardation, normal backwardation, contango* and *normal contango* (Table 1). Each of these states is described based on the relationships between spot, expected spot and observed future prices (Trück et al, 2012).

Table 1. Future market states (Trück et al, 2012)

Future market state	Relationship
Backwardation	$F_{t,T} \leq S_t$
Normal backwardation	$F_{t,T} \leq E(S_T)$
Contango	$F_{t,T} > S_t$
Normal contango	$F_{t,T} > E(S_T)$

The standard model used for pricing commodity future contracts and to explain the relationship with spot price is based on the theory of storage. For commodities these storage costs are driven by the interest rate and storage costs which form the basis of carrying costs for future contracts. The relationship between the spot and future prices and dependency on these variables is generally known as the *cost-of-carry relationship* and is widely used for pricing future contracts for wide range of assets such as stocks, bonds and commodities. The model assumes no arbitrage possibilities between spot and future market, hence the future price can be derived based on the storage costs and any risk-free interest rate foregone (Fama and French, 1987).

3.3 Convenience yield

Pindyck argued that in addition to the storage and interest costs referred as the cost of carry, the future price is also influenced by the benefit of holding an inventory to mitigate supply shortages and sudden price volatility (Pindyck, 2001). The benefit is argued to reflect the availability of the underlying commodity in the future and ability to meet unexpected demand fluctuations. This marginal benefit of holding physical storage is expressed as convenience yield. The convenience yield is argued to reflect the marginal benefit or drawback of physically holding the underlying commodity or asset for the purpose of using it in the future straight from the inventory instead of holding a similar future contract (Kremser and Rammerstorfer, 2010). According to Hull the convenience yield is "*a measure of the benefits from ownership of an asset that are not obtained by the holder of a long futures contracts on the asset*" (Hull, 2012).

Pindyck has derived a formula for the convenience yield based on the cost- of-carry model and assuming that no arbitrage opportunities exist. If no arbitrage opportunities exist, it is possible to obtain risk-free return by buying and holding the underlying asset from t to T and by entering at the same time into a short future contract as the aggregate position is risk free.

To prove this, Pindyck first suggests to assume a capitalized flow of marginal convenience yield $\psi_{t,T}$ over a period from *t* to *t*+*T* and storage cost $k_{T.}$. The stochastic return from holding the commodity is then expressed as:

$$\psi_{T,t} + S_T - S_t - k_T \quad (1)$$

Similarly, the short future contract entered at the same time would provide the return as per equation 2 below.

$$F_{t,T} - \ F_{T,T} = F_{t,T} - S_T \quad (2)$$

The combination of these two returns is non-stochastic and as no cash outlays prior to the settlement are required for the futures contract, the total return equals to risk-free return over the period from *t* to *T*:

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

The convenience yield can be solved as per the equation below as defined by Pindyck:

$$\psi_{T,t} = \ S_t e^{r(T-t)} - \ F_{t,T} + k_T \quad (4)$$

The analogue noted by Pindyck is, that the convenience yield associated with holding the commodity can be related to stock dividends, thus the relative ratio of $(\psi_{T,t} - \ k_T) \ / \ S_t$ is analogous to dividend yield for stocks. (Pindyck, 2001).

Wide range of markets and commodities have been researched and tested for the existence and significance of convenience yield. According to

Kremser & Rammerstorfer both the convenience yield and risk premium can be observed on European and US natural gas markets (Kremser & Rammerstrofer, 2010). Convenience yield is suggested to cause the interest rate bias for non-metal commodities (Brooks et al., 2013). In a multi-commodity analysis covering 31 commodities between 1971 and 2010, Gorton et al concluded that a negative non-linear relationship does exist between convenience yield applied in future pricing and level of inventories (Gorton et. al 2012). In the next chapter we discuss the findings on emission markets in more detail which inspired the research methodology applied in this thesis.

3.4 CO2 allowance future price premiums

The literature regarding emission allowance future pricing and price or risk premiums in general is relatively sparse, except in the context of EU ETS where the availability of historical data has enabled research efforts. The characteristics of the emission allowance market is claimed to be different when compared to other types of commodities due to reliance on regulation and political support.

CO2 allowances are traded as non-physical emission rights and there is no physical stock required to be held in storage. There is no storage cost associated with emission allowances and therefore the storage cost term in standard commodity cost-of-carry based future pricing model is zero. Secondly, banking restrictions and changes in volumes freely allocated allowances between different compliance phases have historically lead to different pricing mechanisms for *intra-phase* and *inter-phase* instruments (Daskalakis, 2009).

As discussed in the previous chapter, there are a number of potential states for future prices. During the pilot trading period (2005 - 2007) the EU ETS market was initially in state of backwardation, which later changed to contango during the Kyoto Compliance period (Phase 2, 2008 - 2012)

(Trück et al., 2012). This observation supports the findings from the study conducted by Daskalakis et al. for Dec09 to Dec12 future contracts during Phase 2, which also indicated the market being mostly in Contango or Normal Contango for that period (Daskalakis, 2009).

Whereas previous research on CO2 allowances has indicated only little statistical evidence for cost-of-carry relationship between *inter-phase (e.g. between Phase 1 and Phase 2)* spot and future prices (Chevallier, 2009), the cost-of-carry model seems to hold for *intra-phase* contracts at least to some extent (Daskalakis et al, 2009) (Daslakis, 2012). Charles et al. have found the futures contracts during Phase 2 to be cointegrated with spot prices and interest rates, although according to their studies the future pricing deviates from cost-of-carry model (Charles et al., 2013).

Most recent studies by Trück et al. support the validity of cost-of-carry pricing, although with relatively significant pricing error suggested to be explained by the convenience yield (Trück et al. 2012). These studies provide reasonable confidence to expect that the spot and future prices are cointegrated at least for intra-period contracts, although mixed conclusions have been made regarding the validity of cost-of-carry model. More interestingly, several different terms have been coined for the pricing error term.

Madaleno and Pinho have found supporting evidence for CO2 future prices to demonstrate significant negative risk premium and positive relationship between the risk premium and time-to-maturity (Madaleno and Pinho, 2011). It is to be noted that their study has adapted and applied the term *risk premium* to describe the overall *forward price premium* as noted earlier by Weron to be the case for numerous other studies on risk premium on power markets (Weron, 2008). The terminology in this sense is not standardized and may reflect the theoretical framework or approach used to conceptualize the phenomena.

The theoretical future price based on the cost-of-carry model does not always align with the observed market price. For CO2 allowances Trück et al. suggest to enhance the cost-of-carry model by adding the residual term $\epsilon_{t,T}$ in the standard equation (denoted as $\psi_{T,t}$ in this study). Additionally, as there are no storage costs due to non-physical nature of the CO2 allowances the cost-of-carry model with convenience yield suggested by Pindyck is proposed to exclude the storage cost k_T (Trück et al. 2012). The model suggested by Trück et al. is then:

$$F_{t,T} = S_t e^{r(T-t)} - \psi_{T,t} \tag{5}$$

It is argued that the residual error term presents convenience yield and reflects the risk premium attributable to the price of emission allowance futures. Compared to some of the other studies, Trück et al. have used daily interest rate quotes from ECB with a similar tenor with the time-to-maturity of the future contract. If the cost-of-carry theory is assumed to hold then the convenience yield is assumed to explain the deviation between the observed future prices and theoretical future prices for CO2 allowances (Trück et al. 2012).

In this study we expect the cost-of-carry model to hold during Phase 2 and Phase 3 for intra-phase contracts and expect any deviation between the observed market future prices and theoretical futures price to be caused by the convenience yield.

A number of studies have explored the factors affecting the future price premium. The model and studies by of Bessembinder and Lemmon on electricity prices suggest the future price risk premium to be positively correlated with the skewness of electricity spot prices and negatively correlated with the variance of the spot price during the contract trading period. Bessembinder and Lemmon associate their findings with traditional theories on risk premium by arguing that the net long hedgers cause contango observed at the same time with price peaks and positive skewness, where as speculators cause backwardation observed in occurrence with high variance (Bessembinder and Lemmon, 2002).

To test the relationship between *ex-post* futures premium ($F_{t,T}$ - S_T) on emission allowance spot price skewness and spot price variance Chevalier applied the model introduced by Bessembinder and Lemmon on EUA futures and spot prices (Chevallier, 2010):

$$F_{t,T} - S_T = \alpha + \beta * SKEW[S_t] + \delta * VAR[S_t] + \epsilon_t \quad (6)$$

Where α is the constant term and the skewness and variance of the spot price are multiplied by the coefficients β and δ respectively. According to Chevallier the future price premium correlates positively with both skewness and variance of the spot price (Chevallier, 2010). This conclusion differs from the relationship proposed by Bessembinder and Lemmon for electricity future price risk premium.

According to Chang the convenience yield of EUAs traded during the Phase 2 correlates positively with the price spread between spot and future contracts. Furthermore, the convenience yield correlates positively with spot price and volatility of the future price, but negatively with the future price and volatility of the spot price. According to Chang this is an indication of pricing bias and overreaction of the market participants to price shocks (Chang, 2014).

The Table 2 summarizes the key findings from literature review regarding emission allowance future price premiums and methodologies applied in each study.

Table 2. Summary of studies regarding CO2 allowance future pricing

Author	EU ETS Periods	Methodologies	Results
Chevallier (2010)	Phase I and Phase II	Regression analysis on future price premium and time to maturity, Bessembinder and Lemmon futures-spot structural model to regress futures premium with variance and skewness of spot price.	Positive relationship between future price risk premium and time to maturity. Positive correlation between both variance and skewness of spot price and risk premium.
Chang (2014)	Phase II	Regression analysis between convenience yield, price spreads, spot price, future price and their volatility.	Convenience yield correlates positively with spot price and future price volatility, and negatively with future price and spot price volatility.
Charles et al. (2013)	Phase I and Phase II	Unit root tests to test non-stationary. Cointegration tests with structural breaks for spot and future prices.	All series integrated of order of 1. Future prices cointegrated with spot prices and interest rates. Future pricing deviates from cost-of-carry model.
Daslakis et al. (2009)	Phase I	Unit root tests, correlation of EUA futures with several other major assets, continuous-time dynamic models.	Intra-phase futures comply with cost-of-carry model. Spot prices show non-stationary and jumps.
Madaleno and Pinho (2010)	Phase I and Phase II	Empirical estimations of risk premium, convenience yield and their relationship.	Negative relationship between risk premium and price volatility. Convenience yield stabilizes as time-to-delivery increases.
Trück et al. (2012)	Phase I and Phase II	Correlation of spot and future price returns, observations on convenience yield. Risk-free interest rate based on daily ECB quotes for different maturities.	Significant convenience yields typical for longer maturities explain deviation from cost-of-carry model. Increasing future price volatility with maturity for both periods.

4. METHODOLOGY

In this chapter we introduce the methodologies applied in the empirical part of this thesis. Some of the methodologies are based on the previous research as discussed in the Chapter 2. First we present the methodology for unit-root testing. Unit-root testing is an essential methodology to analyze the order of integration of both spot and future price series before testing for cointegration. The cointegration is then tested with Johansen cointegration test to observe market efficiency.

As we enhance some of the previous studies with more robust methodology to calculate the risk free rate used in the cost-of-carry model we explain how the interest rate curve has been calculated by using the Nelson-Siegel-Svensson model based on the parameters published daily by the European Central Bank (ECB). The convenience yield is calculated in accordance with the model presented by Pindyck (Pindyck, 2001) and in a similar manner to study conducted by Trück et al (Trück et al, 2012). The resulting convenience yield time series is then used to explain deviation from the standard cost-of-carry model and further analyzed.

We test the relationship between the convenience yield and time to maturity in accordance with the studies and model introduced by Madaleno and Pinho (Madaleno and Pinho, 2011). Finally, we apply the regression model used by Chang to test the factors influencing the convenience yield as an explanatory factor to future price premiums. The factors included are spot price, future price, spot price volatility and future price volatility (Chang, 2014).

4.1 Unit root test

Stationary processes are stochastic processes, which exhibit constant probability distributions, means and covariances. These processes do not follow any time-varying trend. Any unexpected changes in variables, referred as *shocks* by Brooks, are expected to have less effect on observations as the time since the shock is increased. Economic data and time series is often non-stationary, which means that the means and variances change over time and do not autocorrect in a similar manner to stationary processes. Regression testing with non-stationary may not provide valid results (Brooks, 2008). From market efficiency point of view, the unpredictability of these statistical variables expressed as being non-stationary can support efficient and random walk pricing where the previous price behavior cannot be used to predict prices in the future.

Commonly used unit root tests are Dickey–Fuller test (DF), Augmented Dickey–Fuller test (ADF), Phillips-Perron test (PP) and Kwiatkowski–Phillips–Schmidt–Shin test (KPSS). The unit root tests are designed to test the existence of stationary in data series by using an autoregressive model to confirm if any unit roots are present. Non-stationary processes contain at least one unit root.

The traditional DF test is only valid if the time series is characterized by an autoregressive process where the error term is white noise. The null hypothesis is that at least one unit root exists ($\phi = 1$) indicated by a t-statistic value greater than the ADF critical value. The alternative hypothesis is that unit root does not exists ($\phi<1$), which can be confirmed by a t-statistic value being less than ADF critical value (Dickey and Fuller, 1979). The following regression test is commonly used to test the hypothesis of $\psi = 0$, since ϕ -1 = ψ (Brooks, 2008):

$$\Delta y_t = \psi y_{t-1} + u_t \qquad (7)$$

The basic DF model has been criticized as the test is only valid if the error term μ_t is white noise. As a response to this issue the model has been augmented by applying *p lags* on the dependent variable. According to Brooks these lags will *“soak up any dynamic structure present in the dependent variable, to ensure that μ_t is not auto-correlated”* (Brooks, 2008). The inclusion of these *p lags* will augment the standard DF model to become an ADF model as per equation 8:

$$\Delta y_t = \psi y_{t-1t} + \sum_{i=1}^{p} \alpha_i \Delta y_{t-1} + u_t \qquad (8)$$

The ADF test only reveals whether the data contain or do not contain one or more unit roots – it does not reveal the number of unit roots as *per se*. To test and reveal the order of integration i.e. the number of unit roots, the test needs to be repeated by using the further differences of y_t in the null hypothesis and lags of the difference if necessary (Brooks, 2008). The number of lags is selected based on the Schwarz Bayesian information criteria (Schwartz, 1978), which is used in Eviews to find the best parameter to fit the model.

4.2 Cointegration test

According to Engle and Granger the linear combination of non-stationary series can be used to analyze the cointegration and long-term relationship between time series in case their combination is stationary (Engle and Granger, 1987). When applied to test spot and future price relationship, this methodology applies an OLS regression to test the relationship between changes in spot and future prices as per equation 9:

$$\Delta y_t = \psi y_{t-1} + u_t \qquad (9)$$

The cointegration testing procedure consists of confirming all variables are at the same levels and I(1), estimating the regression with OLS and lastly testing the residuals for stationary. The residuals can be then used as variables in the error correction model.

According to Brooks, the Engle and Granger approach has a number of limitations. With small samples there is a typical issue with lack of power in unit root and cointegration test. Secondly, if the causality is bi-directional there may be an issue with simultaneous equations bias as the method forces to use one variable as the dependent and other as independent variables. Thirdly, hypothesis tests about the actual cointegrating relationship are limited (Brooks, 2008). The limitations can be avoided with more sophisticated cointegration tests such as Johansen cointegration test.

In Johansen cointegration test method, the equation 10 representing the vector autoregressive model (VAR) with k lags needs to be first converted into vector error correction model (VECM). According to Brooks the VAR model can be expressed as:

$$\underset{g*1}{y_t} = \underset{g*gg*1}{\beta_1 y_{t-1}} + \underset{g*gg*1}{\beta_2 y_{t-1}} + \dots + \underset{g*gg*1}{\beta_k y_{t-k}} + \underset{g*1}{u_t} \quad (10)$$

The VECM model is then expressed in a form expressed as equation 11 where $\prod = (\sum_{j=1}^{k} \beta_i) - I_g$ and $\prod = (\sum_{j=1}^{i} \beta_j) - I_g$

$$\Delta y_t = \prod y_{t-k} + \prod_1 \Delta y_{t-1} + \prod_2 \Delta y_{t-2} + \cdots + \prod_{k-1} \Delta y_{t-(k-1)} + u_t \quad (11)$$

The eigenvalues for the $\prod$ long run coefficient matrix reveal critical information regarding the cointegration between each series. The cointegration test is based on the rank of the $\prod$ matrix, which is the number of the non-zero eigenvalues. The eigenvalues are sorted in ascending order and they should be between zero and 1. Rank of not significantly greater than zero for the $\prod$ will indicate that the series are not cointegrated (Brooks, 2008).

The test statistics are based on the equation 12 for trace statistics and equation 13 for maximum eigenvalue test statistic. In both equations λ_i represents the value of the eigenvalue of the order *i* from the long run coefficient matrix (Johansen, 1988).

$$\lambda_{trace} = -T\sum_{i=r+1}^{g}\ln(1-\widehat{\lambda_i}) \quad (12)$$

$$\lambda_{\max} \ (r, r+1) = -Tln(1 - \lambda_{r+1}) \quad (13)$$

The test for the r cointegrating vectors is performed in sequences until the null hypothesis cannot be rejected. The hypotheses for the term λ_{max} are formed for each r between zero and g-1 as per the set of equations 14 below (Brooks, 2008):

H0: r = 0	vs.	H1		(14)
H0: r = 1	vs.	H1:		
H0: r = 2	vs.	H1:	2 < r	
..				
H0: r = g-1	vs.	H1:	r = g	

4.3 Nelson–Siegel–Svensson yield curve model

We take one step further compared to the some of the previous studies and use a more accurate proxy for the risk free rate in a similar manner to study conducted by Trück et al. For each future price time-to-maturity we use a similar tenor for risk free rate based on a risk free interest rate curve (Trück et al. 2012). The risk free forward curve is calculated based on the daily updated parameters published by the European Central Bank (ECB).

For the purpose of calculation of the interest rate curve the standard methodology used by ECB is the Svensson model. Svensson suggests the forward curve and yield y_t to be approximated with the following extended Nelson-Siegel model, known as the Nelson-Siegel-Svensson model that has become a widely accepted interpolation methodology for interest rate curves. (Svensson, 1994):

$$y_t = \beta_0 + \beta_1 \frac{1-\exp\left(-\frac{n}{t_1}\right)}{\frac{n}{t_1}} + \beta_2 \left[\frac{1-\exp\left(-\frac{n}{t_1}\right)}{\frac{n}{t_1}} - \exp\left(-\frac{n}{t_1}\right)\right] + \beta_3 [\frac{1-\exp\left(-\frac{n}{t_2}\right)}{\frac{n}{t_2}} - \exp\left(-\frac{n}{t_2}\right)]$$

(15)

Parameters *β2* and *t2* are used in the third term as an extension to the original Nelson-Siegel model where *n* is the maturity, *β0, β1, β2, t1* and *t2* are the parameters to be fitted.

4.4 Theoretical future prices and convenience yield

We calculate the theoretical future price on each trading day based on the end-of-day spot price for future contracts and daily nominated interest rate in accordance with the cost-of-carry model. The convenience yield (denoted with $\psi_{T,t}$) is then calculated based on the difference between the theoretical calculated future price and the actual end-of-day future price as an absolute value:

$$\psi_{T,t} = S_t e^{r(T-t)} - F_{t,T} \quad (16)$$

For a better comparison we then calculate the relative value which indicates the observed price premium and deviation from the standard cost-of-carry model. The relative convenience yield value (γ_t), argued to resemble relative yield in a similar manner to dividend yield on stock, is calculated by dividing the absolute convenience yield by the prevailing spot price:

$$\gamma_t = \psi_{t,T} / S_t \quad (17)$$

4.5 Convenience yield and time to maturity

Previous studies on emission allowance futures suggest that the future price risk premium is time-varying and correlates with time-to-maturity (Chevallier, 2010) (Madaleno and Pinho, 2011). The argument is that as the maturity is approached, the reduced uncertainty is reflected as a vanishing risk premium as more information is obtained.

As it is argued that the convenience yield reflects risk premium for CO2 allowances (Trück et al. 2012), we test the same relationship between the relative convenience yield and time to maturity with the following regression model applied by Chevallier and modify the terms to replace risk premium term with convenience yield (Chevalier, 2010).

$$\gamma_t = \alpha + \beta T_t + \epsilon_t \tag{18}$$

Where α is the constant term, T_t is the remaining time-to-maturity of the future contract and ϵ_t is a Gaussian white noise error (mean 0, variance σ^2).

4.6 Convenience yield and price volatility

According to Chang the convenience yield is positively correlated with spot price and future price volatility and negatively correlated with the future price and spot price volatility. Chang argues that emission allowances markets exhibit pricing bias and that market information influences spot and future prices with different speed. Chang also suggests that the convenience yield reflects properties typical for options as volatility and price shocks drive the level of convenience yield (Chang, 2014).

We test this relationship with the following regression model similar to model tested by Chang by using the absolute convenience yield (Chang, 2014):

$$\psi_{T,t} = \alpha + \beta_1 s_t + \beta_2 \sigma^2{}_{st} + \beta_3 f_t + \beta_4 \sigma^2{}_{ft} + \epsilon_t \qquad (19)$$

Where σ^2 denotes the volatility of spot and future prices and ϵ_t denotes the Gaussian white noise error (mean 0, variance σ^2).

5. DATA DESCRIPTION

The daily spot and future price data for emission allowances traded on the secondary market under the EU ETS was obtained from European Energy Exchange (EEX) market portal and databases covering both Phases 2 and Phase 3. Future contracts traded during Phase 2 and Phase 3 exist for several maturities, typically settling at the end of the calendar year. As described earlier Phase 1 is excluded from this thesis. The carbon allowance market is relatively new and a number of market places have existed during the life span of the scheme. EEX is currently one of the main active carbon exchanges, in addition to Intercontinental Exchange (ICE). This study will focus on the EUA Spot (EUSP) and EEX EUA Future (FEUA) instruments. The underlying unit for these instruments is a single emission permit that can be used to offset one tCO2-e (tons of carbon dioxide equivalent) of emissions otherwise attracting a penalty payment. The phases and their start and date dates are described in Table 3.

Table 3. EU ETS Phases and dates

EU ETS Compliance period	Start date	End date
Phase 1	1 January 2005	31 December 2007
Phase 2	1 January 2008	31 December 2012
Phase 3	1 January 2013	31 December 2020

The data obtained from EEX contains prices for weekdays as the trading days only. The end-of-day settlement price is used as EUA Spot price. EUA Futures settle in mid-December for each corresponding contract maturity (e.g. Dec-14 future settles on 15 December 2014) as illustrated in the Table 4 below.

Table 4. EUA Future contracts and last trading days

Contract	Last trading day
Dec-10	24 December 2010
Dec-11	19 December 2011
Dec-12	17 December 2012
Dec-13	16 December 2013
Dec-14	15 December 2014
Dec-15	14 December 2015

The future price index for each future contract was arranged in order to perform time series analysis aligned with the spot price strip. Both absolute nominal prices and logarithmic return series were used in the analysis where applicable. The daily spot and future prices were converted to logarithmic daily return series by applying natural logarithm in accordance with equation 20.

$$R_t = ln(\frac{S_t}{S_{t-1}}) \quad (20)$$

5.1 Data statistics

Due to underlying differences in market mechanisms and differences between EU ETS phases we first analyzed and summarized the spot prices and daily returns for Phase 2 and Phase 3 in isolation (Table 5). The mean values of spot series vary from 13.6715 for Phase 2 to 4.7514 for Phase 3. The mean values of daily log return series are -0.0010 or -0.1% for Phase 2 and -0.0009 or -0.09% for Phase 3.

The most volatile daily spot price movements have been experienced during Phase 3 expressed as a maximum 0.2019 and a minimum -0.4097. For Phase 2 the maximum and minimum daily movements have been 0.1870 and -0.1153 respectively. The visual inspection of Figure 3 confirms that the spot price decreased consistently during the turmoil of the global financial crisis. The Phase 2 and Phase 3 spot price data sets have relatively similar Kurtosis of 3.4084 and 3.2560 respectively.

During the Phase 2 most of the daily returns have been less than the mean as indicated by the positive value for Skewness, unlike during Phase 3 for which most of the returns have been higher than mean. In Figure 1 we can see that the spot price has been trending downwards during Phase 2. During Phase 3 this trend is less obvious, albeit relatively significant short time movements have still occurred as indicated by the range of daily returns.

Table 5. Summary statistics of spot prices

	EUA Spot - Phase 2		EUA Spot - Phase 3	
	S_t	R_t	S_t	R_t
N	1213	1212	318	318
Mean	13.6715	-0.0010	4.7514	-0.0009
Median	13.7800	-0.0004	4.5850	0.0000
Maximum	28.7500	0.1870	7.1100	0.2019
Minimum	5.7000	-0.1153	2.7200	-0.4097
Std. Dev.	5.0749	0.0280	0.8859	0.0526
Skewness	0.7754	0.1114	0.5489	-1.3061
Kurtosis	3.4084	6.5809	3.2560	15.3699

During Phase 2 and Phase 3 the spot price has decreased from approximately 20 euros in 2008 (Phase 2) to approximately 5 euros in April 2014 (Phase 3) as visible in Figures 3 and 4. The EUA price levels in early 2008 reflected relatively high oil prices followed by economic recession and global financial crisis causing deep decline in EUA prices by 2009 (Taylor, 2010). Based on visual inspection of daily spot log return graphs the spot price features non-constant variance and heteroscedasticity. Interestingly, the log return graph (Figure 6) for Phase 3 indicates relatively significant movements in daily spot price in early 2013 when EU ETS transitioned from Phase 2 to Phase 3.

Figure 3. EUA Spot price during Phase 2

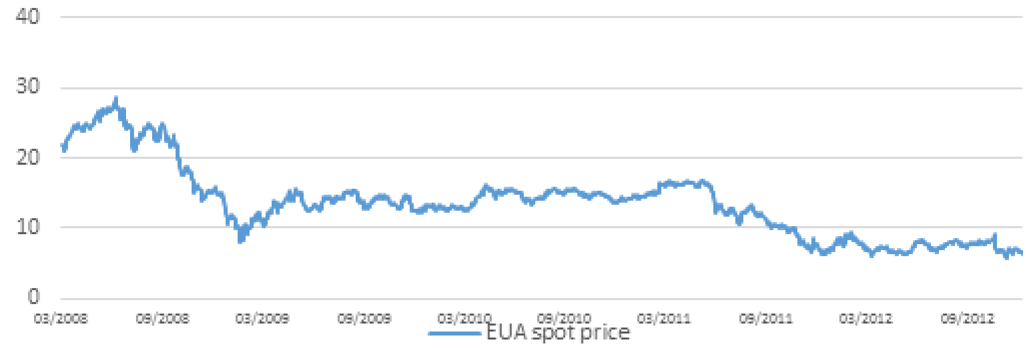


Figure 4. EUA Spot daily log return during Phase 2

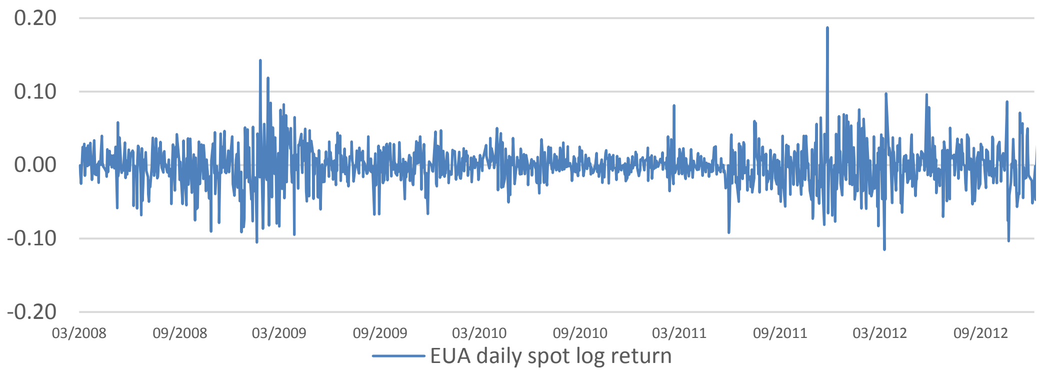


Figure 5. EUA Spot price during Phase 3

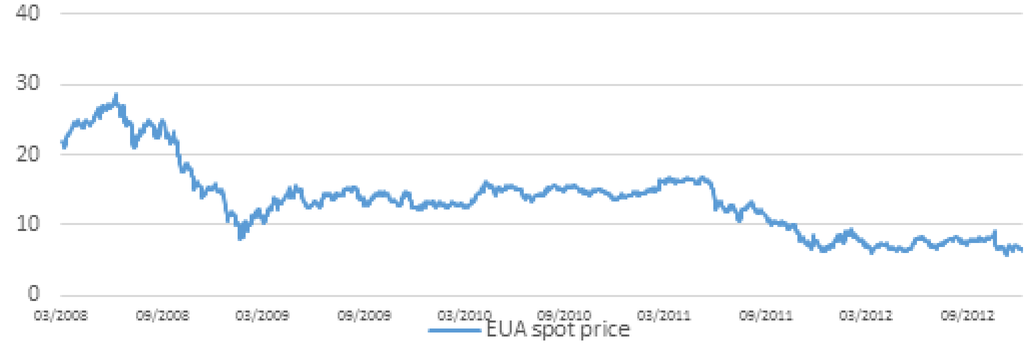
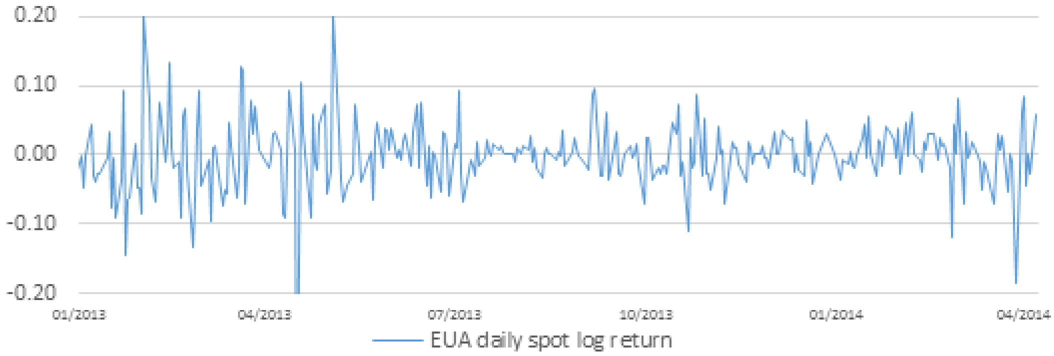


Figure 6. EUA Spot daily log return during Phase 3



The future contracts generally exhibit similar statistics to spot price, however their values align only with partial periods of spot prices attributed to Phase 2 and Phase 3. This is due to limited life span of the future price series and varying start and expiry dates of the future contracts. Analogous to the kurtosis of the spot price daily logarithmic returns (6.5809 in Phase 2 vs. 15.3699 in Phase 3) the kurtosis of future price daily returns has increased from 5.4308 (Dec-10 contract) to 22.6983 (Dec-15 contract). This is a promising finding prior to proceeding with the actual cointegration tests. It must be noted that Dec-15 contract has been traded since January 2010, covering both Phase 2 and Phase 3.

Table 6. Summary statistics of future prices

Absolute values	Dec-10	Dec-11	Dec-12	Dec-13	Dec-14	Dec-15
n	299	552	805	883	958	828
Mean	14.3632	14.1629	12.4876	10.3068	10.4859	9.8925
Std. Dev.	0.9871	2.1850	3.8651	5.1560	5.4212	5.2750
Skewness	-0.2569	-1.2161	-0.3216	0.3476	0.4622	0.8707
Kurtosis	1.8387	4.4212	1.4981	1.6342	1.7294	2.5707
Daily log returns	Dec-10	Dec-11	Dec-12	Dec-13	Dec-14	Dec-15
N	299	552	805	883	958	828
Mean	-0.0002	-0.0014	-0.0012	-0.0015	-0.0013	-0.0015
Std. Dev.	0.0170	0.0205	0.0258	0.0370	0.0372	0.0387
Skewness	-0.5948	-0.6954	0.0659	-1.1798	-1.2624	-1.3357
Kurtosis	5.4308	5.8715	7.8768	25.6859	24.0860	22.6983

The standard deviation for Dec-15 future daily returns is 0.0387 compared to 0.0170 for Dec-10 contract. Interestingly, the standard deviation is higher for future contracts with maturity date further in the future. Again, this may be due to period the underlying contract is traded, as the same trend is observable for the spot prices.

The Table 7 below summarizes the number of days when the future price has traded below spot price (backwardation) or above spot price (contango) for each different future contract type covered by this thesis. The future prices have featured backwardation for Dec-10 and Dec-11 contracts, however once the scheme has moved to Phase 3 the contango has become the dominant state. This indicates that during Phase 3 the convenience yield has been mostly negative.

Table 7. Future price observations and states

	Dec-10	Dec-11	Dec-12	Dec-13	Dec-14	Dec-15
Observations	299	552	805	883	958	828
Start date	26/10/09	26/10/09	26/10/09	3/6/10	3/6/10	29/12/12
Close date	24/12/10	19/12/11	17/12/12	16/12/13	7/4/14	7/4/14
Contango obs.	197	541	789	875	958	828
Backwardation obs.	102	11	16	8	0	0

The graphs in Figures 7 to 9 below illustrate the spot price during Phase 1 and Phase 2 and several historical future price curves for different contracts during periods they were traded. Visual examination of the curves reveals that the future prices follow and reflect the movement of spot prices. The diminishing spread between future price and spot price can be observed, as the future prices converge with spot prices as the future contracts approach maturity. This is the first clue that at least some level of cointegration and alignment with the cost-of-carry pricing model does exist, but also an indication of time-varying deviation.

Figure 7. Dec-14 Future and Spot price

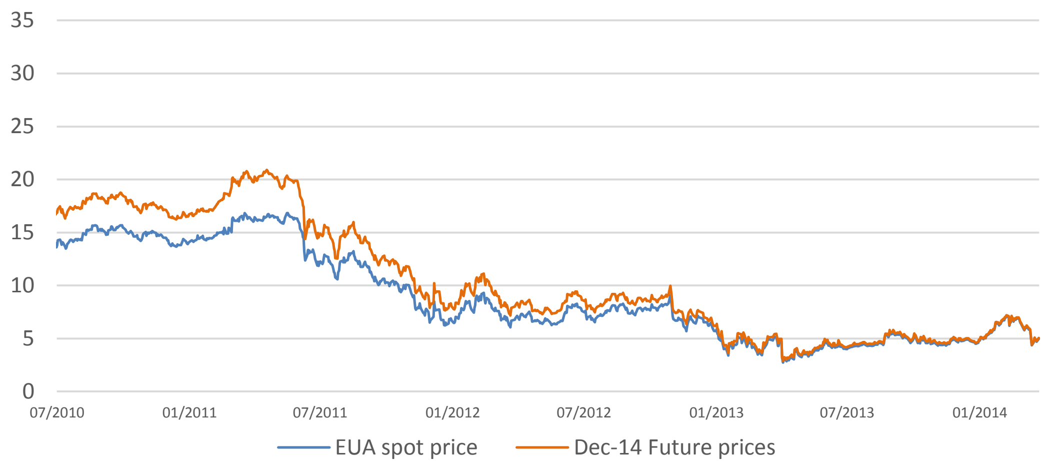


Figure 8. Dec-13 Future and Spot price

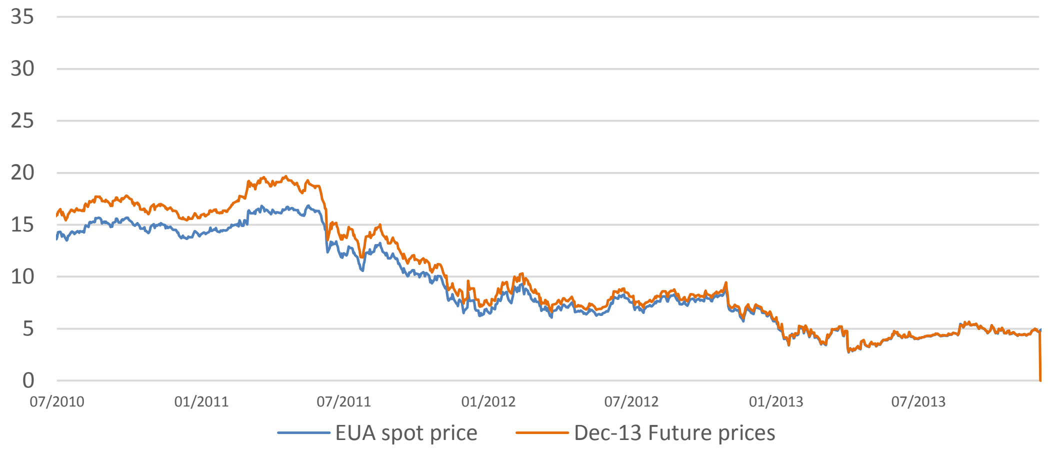
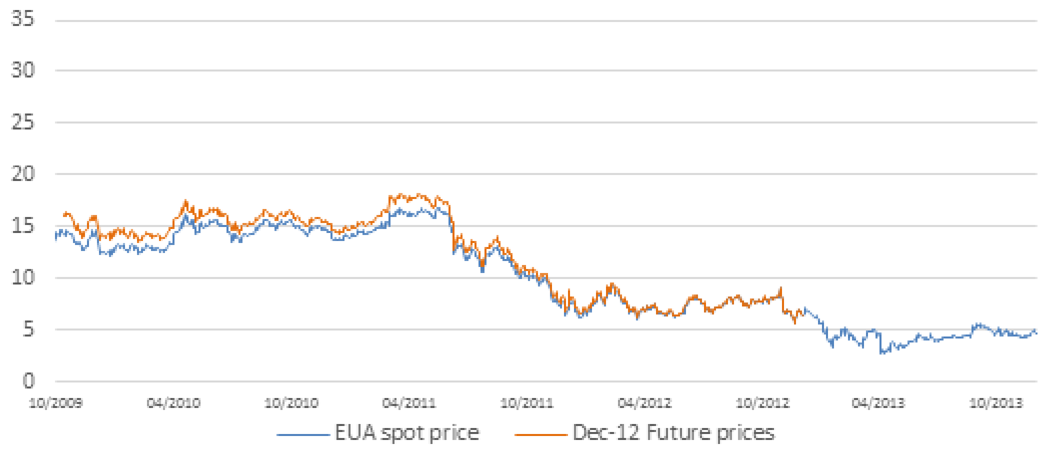


Figure 9. Dec-12 Future and Spot price



6. EMPIRICAL RESULTS

In this section we present the results obtained from each test. First, we discuss the unit root test and cointegration test results. Then, we analyze the relationship between convenience yield and time to maturity. Lastly, we deploy similar regression testing to Chang to explore the correlation between spot price, future price and volatility of spot and future prices and convenience yield.

Theoretical value of the future price for each contract maturity was calculated with the cost-of-carry model, prevailing spot price and interest rate. The interest rate was calculated for each trading day with a matching time to maturity with the theoretical future contract value. As discussed earlier the volatility of spot and future prices were based on historical rolling daily prices due to limitations regarding intra-day spot price data. We applied two different sample period length parameters for the historical volatility.

6.1 Unit root test

We employed the Augmented Dickey-Fuller test to confirm the number of unit roots and verify the stationary or non-stationary of the spot and future prices. The test for unit roots is of a particular interest prior to further cointegration tests as such tests typically require the data sets to be on the same levels in terms of order of integration. The ADF test was conducted for both absolute price series (denoted with p) and return series (denoted with r) and separately for Phase 2 and Phase 3. Tests are run with no intercept or trend in data, only intercept in data and both intercept and trend in data for completeness. The lag length parameter in the ADF model is selected by using the Schwarz Bayesian information criteria. The results of the ADF tests are illustrated in Table 8.

Table 8. Unit root test of spot and future prices and returns

	No Intercept or trend		Intercept only		Intercept and trend	
	p_{phase2}	p_{phase3}	p_{phase2}	p_{phase3}	p_{phase2}	p_{phase3}
Spot	0.80	0.01	-1.08	-1.95	-1.95	-1.78
Dec-15	1.03	0.11	-0.90	-1.94	-1.53	-1.76
Dec-14	1.06	0.08	-1.04	-1.99	-1.67	-1.81
Dec-13	1.03	0.24	-1.02	-1.83	-1.69	-1.74
Dec-12	0.77	N/A	-1.39	N/A	-1.71	N/A
Dec-11	0.83	N/A	-3.31*	N/A	-2.85	N/A
Dec-10	-0.34	N/A	-3.48**	N/A	-3.98*	N/A
	r_{phase2}	r_{phase3}	r_{phase2}	r_{phase3}	r_{phase2}	r_{phase3}
Spot	-34.08**	-15.47**	-34.10**	-15.45**	-34.09**	-15.46**
Dec-15	-20.85**	-14.93**	-20.89**	-14.91**	-20.87**	-14.93**
Dec-14	-24.19**	-15.02**	-24.23**	-15.00**	-24.21**	-15.02**
Dec-13	-24.20**	-13.32**	-24.24**	-13.30**	-24.23**	-13.37**
Dec-12	-27.52**	N/A	-27.56**	N/A	-27.55**	N/A
Dec-11	-22.02**	N/A	-22.10**	N/A	-22.28**	N/A
Dec-10	-16.81**	N/A	-16.79**	N/A	-16.76**	N/A

** denotes significance at 1% level, * denotes significance at 5% level

N/A denotes contracts that have matured prior to Phase 3

With the exception of Dec-11 and Dec-10 futures traded during Phase 2 when tested with intercept, all other absolute values demonstrate non-stationary as the null hypothesis for ADF test cannot be rejected. This outcome can be observed from Figure 2 that shows visible time varying trend, except for period when Dec-11 and Dec-10 contracts were traded. During that time the prices have been stationary and prices been relatively constant. At first difference, the absolute value series demonstrate stationary as the test values are below critical values, hence they are integrated at the same level of I(1) and suitable for Johansen cointegration test. These results align with Charles et al who concluded that all future contract series (Dec-09 to Dec-12) covered by their study contained a unit root and were integrated of order of one (Charles et al, 2013).

We reject the ADF null hypothesis for all return series as the test values are clearly higher than critical values. The return series are stationary and can be considered to be random. The test values are systematically lower for future returns during Phase 2 when compared with values for Phase 3.

6.2 Cointegration tests

Johansen cointegration test was deployed to test the cointegration of spot and future prices during Phase 2 and Phase 3 on different future maturities. As both spot and future price series were found to be integrated at the same level of I(1) and being non-stationary, we were able to proceed with Johansen cointegration test.

The maximum number of cointegrating vectors can be one as we only selected a pair of price series consisting of spot and future price that were tested for cointegration. First, we tested for cointegration based on the assumption of no linear trend or intercept in data and a lag interval assumption of one. The null hypothesis of no cointegrating vectors ($r=0$) was rejected for all futures contracts traded during Phase 2, with multiple trace statistic values being significant at 5% level. The hypothesis on the existence on cointegrating vector was not rejected. For a period covering Phase 3, the null hypothesis of zero cointegrating vectors was rejected only for Dec-13 future contract, whereas on both Dec-14 and Dec-15 contracts the null hypothesis could not be rejected due to low trace test values.

To further investigate the potential deterministic trend and intercept in cointegration vector we run the cointegration test assuming linear trend and intercept in cointegration vector, but no with no interception in VAR. The null hypothesis was rejected for all future contracts traded during Phase 2, except Dec-14 and Dec-15 contracts. However, the null hypothesis could be rejected for all future contracts traded during Phase 3, including Dec-14 and Dec-15 contracts, and the hypothesis on existence of one cointegrating vector could not be rejected. The results of both cointegration tests are presented in Table 9 below.

Table 9. Johansen cointegration test results

No linear trend, no intercept in cointegration vector

	Dec-10		Dec-11		Dec-12		Dec-13		Dec-14		Dec-15	
Phase 2												
r	Trace	Max	Trace	Max	Trace	Max	Trace	Max	Trace	Max	Trace	Max
0	47.73*	47.73*	27.18*	26.94*	12.53*	12.16*	13.06*	12.29*	14.40*	13.54*	15.65*	14.46*
1	0.00	0.00	0.25	0.25	0.36	0.36	0.77	0.77	0.86	0.86	1.19	1.19
Phase 3												
r	Trace	Max	Trace	Max	Trace	Max	Trace	Max	Trace	Max	Trace	Max
0	-	-	-	-	-	-	20.94*	20.88*	5.44	5.17	5.73	5.34
1	-	-	-	-	-	-	0.07	0.07	0.27	0.27	0.39	0.39

Linear trend, intercept in cointegration vector

	Dec-10		Dec-11		Dec-12		Dec-13		Dec-14		Dec-15	
Phase 2												
r	Trace	Max	Trace	Max	Trace	Max	Trace	Max	Trace	Max	Trace	Max
0	57.78*	49.68*	69.96*	57.64*	31.53*	28.39*	30.74*	27.46*	24.31	21.06*	18.42	15.32
1	8.10	8.10	12.32	12.32	3.14	3.14	3.28	3.28	3.25	3.25	3.10	3.10
Phase 3												
r	Trace	Max	Trace	Max	Trace	Max	Trace	Max	Trace	Max	Trace	Max
0	-	-	-	-	-	-	80.86*	75.49*	43.26*	38.57*	36.13*	32.12*
1	-	-	-	-	-	-	5.37	5.37	4.69	4.69	4.01	4.01

* denotes rejection of the hypothesis at the 5% level

Based on the Johansen cointegration test results it can be concluded that the spot and future prices have been cointegrated during Phase 2, especially if no linear trend or intercept in cointegration vector is assumed. Noticeably the trace value for Dec-14 and Max value for Dec-15 contracts are not statistically significant in case a linear trend and interception are assumed.

During Phase 3 and with the exception of Dec-13 contracts there is only indication of cointegration if linear trend and intercept in cointegration vector are assumed. Overall our second Johansen test results in higher trace values, albeit anomalies with statistical significance for Dec-14 and Dec-15 contracts during Phase 2 existed. The trace values tend to be higher for earlier future contracts, which can be observed for both Phases. The results comply with earlier tests by Charles et al. with a similar trend of higher trace test values for earlier future contracts during Phase 2 (Charles et al, 2013).

6.3 Convenience yield and time to maturity

The convenience yield was calculated as the difference between actual and theoretical future price for each trading day and converted to relative value by dividing the difference by the actual spot price. The visual inspection of the time series (see Figures 6 to 8) supports the intuition that the convenience yield gradually diminishes as settlement date of the future contract is approached, however there appears to exist periods where the relationship may not hold.

We tested for the correlation between convenience yield and time to maturity by using the standard Ordinary Least Squares (OLS) method with convenience yield as the dependent variable and time to maturity as regressors as per equation 18 presented earlier. As the visual inspection of the convenience yield over time indicated potentially different behavior between Phase 2 and Phase 3, we decided to run the regressions on both cross-phase and intra-phase time basis. Of the future contracts selected, Dec-10, Dec-11 and Dec-12 matured prior to Phase 3 hence they could be only tested on intra-phase (Phase 2) basis. The regressions results are presented in Table 10.

During Phase 2 the coefficient β suggests positive correlation between time to maturity and convenience yield. However, the correlation coefficients are relatively small with 0.0003 for Dec-10 being the biggest. The null hypothesis of the time to maturity coefficient being zero was not rejected for Dec-10 and Dec-11 contracts. The R-squared values are low, except for Dec-14 and Dec-15 contracts, indicating higher variance and deviation of samples from the regression trend line. In long term there seems to be no generalizable correlation between convenience yield and time to maturity during Phase 2. During Phase 2 July 2012 seems to be a tipping point in regards to the time varying nature of the convenience yield.

Table 10. Regression of convenience yield and time to maturity

	Dec-10	Dec-11	Dec-12	Dec-13	Dec-14	Dec-15
Cross-Phase (Phase 2 and 3)						
R-Squared	n/a	n/a	n/a	0.3834	0.1591	0.1714
F-statistic	n/a	n/a	n/a	1972.49	1753.85	1375.83
Coefficient - α	n/a	n/a	n/a	-0.0195**	-0.0406**	-0.0376**
Coefficient - β	n/a	n/a	n/a	-0.0001**	0.0000**	-0.0001**
Intra-phase (Phase 3)						
R-Squared	n/a	n/a	n/a	0.5204	0.8247	0.6492
F-statistic	n/a	n/a	n/a	261.53	1486.82	584.81
Coefficient - α	n/a	n/a	n/a	0.0015	0.0248**	0.0323**
Coefficient - β	n/a	n/a	n/a	-0.0001**	-0.0001**	-0.0001**
Intra-phase (Phase 2)						
R-Squared	0.0119	0.0021	0.0089	0.0087	0.3686	0.3037
F-statistic	3.58	1.15	7.20	5.57	372.41	221.56
Coefficient - α	-0.1178	-0.0123*	-0.0224**	-0.0778**	-0.1950**	-0.3111**
Coefficient - β	0.0003	0.0000	0.0000**	0.0000*	0.0001**	0.0001**

**denotes significance at 1% level, * denotes significance at 5% level

During Phase 3 the coefficient β suggests negative correlation between time to maturity and convenience yield. P-values are well above the critical values for 1% significance level. The R-squared numbers ranging from 0.5204 for Dec-13 contract to 0.6492 for Dec-15 contract suggest less variability around the regression trend. The results indicate negative correlation between convenience yield and time to maturity during Phase 3. It is noted that Phase 3 regressions cover a smaller number of historical trades, whereas the Phase 2 regressions cover all trading dates for Dec-13 contract as an example. Including all trading days may bias the results as the correlation may be more dominant closer to maturity and delivery date.

The Cross-Phase regressions indicate negative correlation between convenience yield and time to maturity, however with low R-squared values. We expected to see less observable correlation in Cross-Phase regressions due to fundamental differences between Phase 2 and Phase 3 and compliance requirements. Banking restrictions between Phase 2 and Phase 3 may have caused different price movements between spot and cross-phase future contracts. Figures 10 to 12 below illustrate the convenience yield, actual and theoretical prices for Dec-13 future contract in Phase 2 and Phase 3. A comprehensive set of graphs is presented in Appendix 1.

Figure 10. Dec-13 Convenience yield (Cross-Phase)

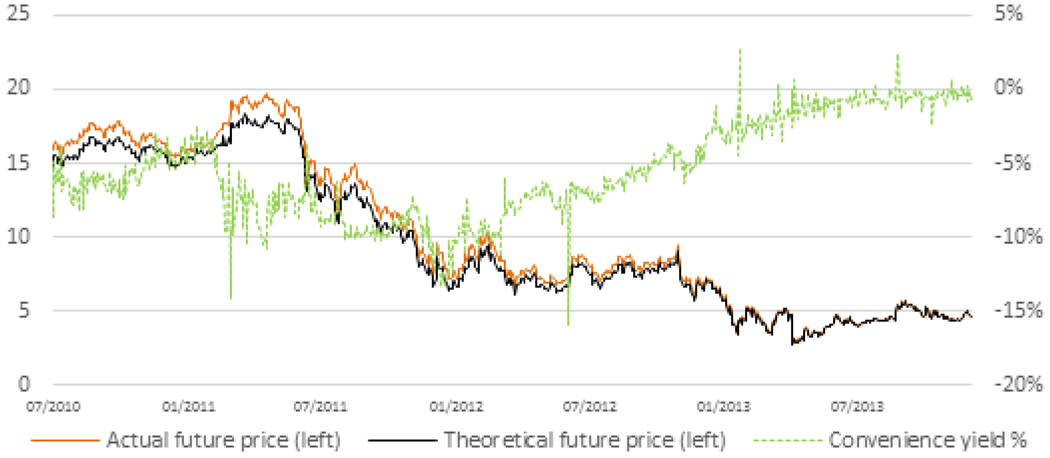


Figure 11. Dec-13 Convenience yield (Phase 3)

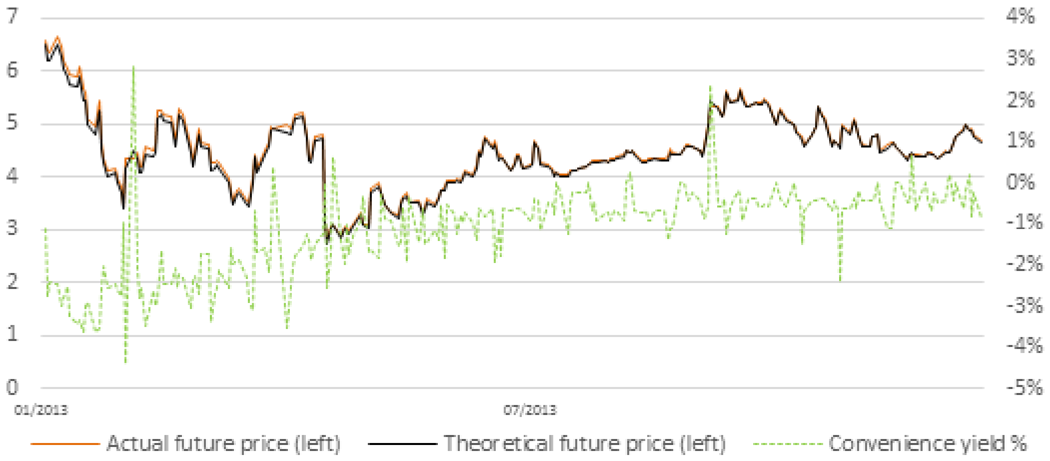
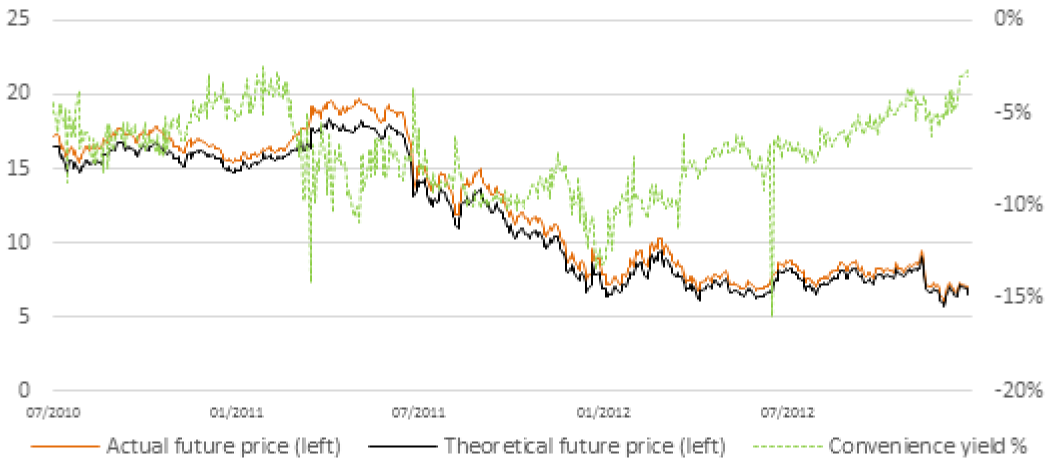


Figure 12. Dec-13 Convenience yield (Phase 2)



6.4 Convenience yield and price volatility

According to Chang the convenience yields for emission allowances traded in EU ETS correlate positively with the spot price and volatility of future price, and negatively with the future price and volatility of spot price (Chang, 2014). We expected similar results to Chang, although our empirical data range extends to Phase 3 and volatility is calculated based on historical prices instead of implied volatility used by Chang. Further, we derived convenience yield based on the daily interest rates whereas Chang used a constant benchmark interest rate.

As discussed earlier, Johansen cointegration test did not provide full statistical evidence and support for cointegration of spot and future prices for Dec-14 and Dec-15 contracts, therefore we exclude them from this part of the analysis. We derived the historical volatility of both spot and future prices by using rolling daily historical prices. For completeness we applied 20 and 40 days as sample length parameters for the historical prices (see Appendix 2. illustrating the volatility graphs). For convenience yield we used the non-relative value i.e. the difference between the theoretical value and actual future price in order to match the regression model introduced by Chang.

Our results with 20 day historical volatility of spot and future prices indicate that the convenience yield for Dec-13, Dec-11 and Dec-10 correlates positively with the spot price and spot price volatility, and negatively with the future price and future price volatility. For Dec-12 contract the second coefficient indicates negative correlation of -0.035 with spot price. Dec-10 future shows most significant positive correlation with spot price at 0.959 whereas for Dec-11 the correlation is only 0.291, both at high significance level. Spot price 20 day historical volatility has a positive correlation with convenience yield and at high significance level. Future price and future price volatility coefficients indicate negative correlation with convenience yield. Dec-10 future price volatility coefficient of -0.090 has the lower significance level of 5%. These results are presented in Table 11.

Table 11. Regression results – convenience yield and 20 day volatilities

	α	β_1	β_2	β_3	β_4	Adj. R2	N
Dec-13 Future							
Coefficient	-0.286**	0.670**	0.609**	-0.626**	-0.729**	0.859	882
t-statistic	-9.676	20.402	4.673	-22.707	-6.339		
Dec-12 Future							
Coefficient	0.176**	-0.035**	0.641**	-0.809**	-0.777**	0.385	804
t-statistic	6.751	-19.587	5.469	-3.480	-7.126		
Dec-11 Future							
Coefficient	0.195**	0.291**	0.521**	-0.311**	-0.484**	0.433	551
t-statistic	4.581	11.791	5.209	-13.376	-5.119		
Dec-10 Future							
Coefficient	0.599**	0.959**	0.206**	-0.999**	-0.090*	0.978	298
t-statistic	11.686	107.278	5.710	-110.318	-2.563		

α denotes intercept, β_1 is the coefficient for spot price, β_2 is the coefficient for spot price volatility, β_3 is the coefficient for future price and β_4 is the coefficient for future price volatility. ** denotes significance at 1% level, * denotes significance at 5% level

The adjusted R squares are relatively high, especially for Dec-13 (0.859) and Dec-10 (0.978) contracts. Next, we run the same regression test with 40 day historical volatilities for completeness. Spot and future price coefficients indicate similar correlations and significance levels. The coefficients for spot price volatility and future price volatility on 40 day basis are similar to 20 day volatilities. The t-statistics indicate similar or higher significance for 40 day volatilities, except for Dec-13 spot price volatility which has a t-value of 3.861 (4.673 with 20 day volatility), still indicating 1% significance level. The results with 40 day volatilities are presented in Table 12.

Table 12. Regression results – convenience yield and 40 day volatilities

	A	β_1	β_2	β_3	β_4	Adj. R2	N
Dec-13 Future							
Coefficient	-0.214**	0.619**	0.337**	-0.584**	-0.482**	0.865	882
t-statistic	-6.912	18.731	3.861	-21.063	-6.324		
Dec-12 Future							
Coefficient	0.234**	-0.035**	0.548**	-0.794**	-0.723**	0.477	804
t-statistic	9.563	-21.479	7.637	-3.703	-10.930		
Dec-11 Future							
Coefficient	0.250**	0.320**	0.451**	-0.340**	-0.470**	0.474	551
t-statistic	5.929	13.261	7.696	-14.972	-8.552		
Dec-10 Future							
Coefficient	0.693**	0.966**	0.310**	-1.013**	-0.217**	0.982	298
t-statistic	15.708	123.638	12.216	-127.900	-9.060		

α denotes intercept, β_1 is the coefficient for spot price, β_2 is the coefficient for spot price volatility, β_3 is the coefficient for future price and β_4 is the coefficient for future price volatility. ** denotes significance at 1% level, * denotes significance at 5% level

An interesting observation when 40 day volatilities are used is that the R squared values are higher when compared with the values obtained by using 20 day volatilities used in the regression test. The coefficients provide similar results when compared with results obtained by using 20 day volatilities, and t-values indicate high significance levels.

Although the convenience yield for all future contracts correlates negatively with the future price and positively with the spot price (with the exception of Dec-12 contract) as suggested by Chang, our results for the correlations between convenience yield and the volatility spot and future are different when compared with the study conducted by Chang. Whereas Chang suggested positive correlation for future price volatility and negative correlation for spot price volatility (Chang, 2014) our results indicate negative correlation for future price volatility and positive correlation for spot price volatility. As discussed earlier, this may be due to different calculation basis for the convenience yield as the convenience yields calculated by Chang are positive and potentially expressed as absolute values. Additionally, the deviation may be caused by different basis for the risk free interest rate, but also different sample period and definition of volatility. Chang used 12-month Euribor as the risk-free interest rate and applied a sample period covering trading dates between 8 April 2008 and 20 December 2010. The study by Chang suggests that convenience yield has similarities with call and put options depending whether the trader benefits of buying on spot and selling futures or vice versa (Chang, 2014).

7. CONCLUSIONS

The objective of this thesis was to research the nature and existence of future price premiums on emission allowances traded in EU ETS. As the estimation of future price premium and convenience yield relies on the cost-of-carry model we tested the cointegration between spot and future prices for various future contract maturities by using Johansen cointegration test methodology. To explore the nature of convenience yield and its time-variant nature we tested the correlation between convenience yield and time to maturity. As supported by some of the previous research, we then tested the correlation between convenience yield and volatility of spot and future prices.

Our journey on the subject began with the presentation of the emission allowance markets and economic theories on emission reduction systems. We concluded that the emission trading markets are evolving rapidly and are subject to political debate and regulatory decisions, which not only influence the existence of these schemes but also the supply and demand mechanism. The price of the emission allowances has been described to be correlated with electricity and energy commodity prices such as natural gas and thermal coal, and ambient temperatures. According to the literature reviewed, there is no evidence for strong correlation with macroeconomic variables.

We then moved into the context of corporate risk management and concluded that as a result of managerial risk aversion, financial distress costs, shareholder preferences and requirements for earnings predictability companies tend to hedge even the theory suggests the performance of the company and value of the company to well diversified shareholders should not depend on these decisions. As GHG emissions are an input to the production cost for liable companies, these companies are interested in managing the price risk by hedging their emission allowance exposures. The future price premiums in the context of emission allowances traded in EU ETS have been studied by a number of authors during the relatively short existence of the scheme. A number of these studies support the cointegration of spot and future prices and the validity of cost-of-carry relationship with deviations explained by either risk premium or convenience yield.

The empirical part of this thesis consisted of unit root testing, cointegration testing of spot and future prices by using Johansen cointegration methodology and regression testing of the correlation between convenience yield and future contract time-to-maturity. To explore the determinants of the convenience yield we regression tested the relationship between convenience yield, spot price, future price, spot price volatility and future price volatility. Sample periods of 20 and 40 days were used for calculating the historical volatilities based on daily spot and future prices.

Our data analysis revealed that the EUA future markets began to feature contango state in Phase 3 having featured both backwardation and contango states during Phase 2. This observation aligns with previous studies (Charles et al, 2013) and is consistent with the negative convenience yield observations. The unit root testing was conducted by applying Augmented Dickey-Fuller test with no intercept or trend, intercept only, and with both intercept and trend. The results indicated that spot and all future absolute price series are non-stationary, except for Dec-10 and Dec-11 with tests results indicating stationary. At first difference all absolute price series demonstrated stationary, hence they were suitable for Johansen cointegration test. This outcome aligned with earlier studies (Charles et al, 2013). All return series demonstrated stationary and can be considered random.

Johansen cointegration tests support the conclusion of spot and future prices being cointegrated during Phase 2, especially if no linear trend or intercept in cointegration vector is assumed. With linear trend and intercept Dec-14 and Dec-15 contracts did not feature strong coingeration.

During Phase 3 there is indication of cointegration only if linear trend and intercept in cointegration vector are assumed. Interestingly, the trace statistic values were higher for earlier future contracts traded during both Phase 2 and Phase 3, similar to statistical values indicated by earlier studies (Charles et al, 2013). This may indicate higher market efficiency and stronger relationship between spot and future prices at the beginning of each phase.

The correlation between convenience yield and time-to-maturity featured positive correlation during Phase 2, albeit the critical values for Dec-10 and Dec-11 future contracts were below the 5% threshold. During Phase 3 the correlations between the convenience yield and time-to-maturity was negative for all contracts traded (Dec-13, Dec-14, Dec-15). This result was to some extend unexpected as previous studies have indicated consistent and one-way time-varying relationship between convenience yield and time-to-maturity (Chevallier, 2010). This result may be caused by the larger sample period in our study covering the entire Phase 2. The time-varying relationship may be only effective for a certain period prior to the maturity of the future contract. The intra-phase correlations resulted in mixed-results as expected due to fundamental pricing differences between Phase 2 and Phase 3 and longer sample period which may bias the effect of time varying convenience yield. The results for Phase 3 and anecdotal evidence during Phase 2 of the negative relationship between convenience yield and time-to-maturity may suggest arbitrage opportunities of buying on spot and entering into a short future position in the absence of storage costs, however overall profitability being subject to transaction costs. It appears that long future contracts entail a price premium which may reflect the required compensation for negative convenience yields perceived by the physical holders of emission allowances.

Our test results indicate that the convenience yields for Dec-13, Dec-11 and Dec-10 contracts correlate positively with the spot price and its volatility. On the other hand the test indicated negative correlation with the future price and future price volatility. These results differ from earlier studies, which have indicated positive correlation with future price volatility and negative correlation with spot price volatility (Chang, 2014). We assume the opposite result to be caused by different calculation method for the convenience yield resulting in opposite values. Controversial results were obtained for Dec-12 contract, where the spot price was negatively correlated. Both 20 and 40 day historical volatilities provided similar results.

The negative convenience yields and dominant contango state of the future markets in Phase 3 may raise a number of questions from the investor point of view, but also some potential policy implications to be considered. The information on allocation plans may impact the price levels in general and is essential information for market participants. Any planned regulatory actions or changes in the scheme are likely to be speculated on the market beforehand with potential impact on price and volatility. This does not only emphasize the importance of equal access to the information from the regulator's side, but it also highlights the need for the market participants to be able to interpret the price sensitive information and act accordingly.

Future research on this subject is welcome, as the relatively short term existence of emission trading schemes and evolving new emission allowance markets provide fertile ground for new research topics. Co-movements of prices between different schemes, convenience yield spreads and arbitrage strategies may be among the topics which may become easier to research once more long-term historical data is available for different schemes.

REFERENCES

Aatola, P., Ollikainen M., Toppinen A. 2013. Price determination in the EU ETS market: Theory and econometric analysis with market fundamentals Energy Economics, Vol 36. 380-395

Air Resource Board. 2014. California Environmental Protection Agency web pages on ETS linkage. Accessed 26 July 2014. Available at: http://www.arb.ca.gov/cc/capandtrade/linkage/linkage.htm

Alderson, M., J., Betker, B., L. 2012. Managerial incentives, net debt and investment activity in all-equity firms. Studies in Economics and Finance. Vol 29, Issue 4. 232-245

Alberola, E., J. Chevallier, and B. Cheze. 2008. Price Drivers and Structural Breaks in European Carbon Prices 2005 – 2007. Energy Policy, Vol 36, No. 2. 787-797

Benz, E., Trück, S., 2006. CO2 emission allowances trading in Europe — specifying a new class of assets. Problems and Perspectives in Management, Vol 4, Issue 3. 30-40

Betz, R. 2006. What is driving Price Volatility in the EU ETS? Reports and Working papers in Australasian Emissions Trading Forum Review. Oct/Nov 2006. 4-5.

Bessembinder, H., Lemmon, M.L. 2002. Equilibrium pricing and optimal hedging in electricity forward markets. Journal of Finance, Vol 57, Issue 3, 1347-1382

Bloch, D. 2010. A note on emissions trading: The pricing of carbon derivatives. Working paper. Université Paris VI Pierre et Marie Curie.

Brooks, C., Prokopezuk, M., Wu, Y. 2013. Commodity Futures Prices: More Evidence on Forecast Power, Risk Premia and the Theory of Storage. The Quarterly Review of Economics and Finance. Vol 53, Issue 1. 73–85

Brooks, C. 2008. Introductory Econometrics for Finance. Second Edition. Cambridge University Press. 648 pages.

Chang, K. 2014. Convenience Yield Value of International Emission Allowance Based on Call Options. Journal of Computational Environmental Sciences. Vol 2014. 5 pages

Chao, H. Wilson, R. 1993. Option value of emission allowances. Journal of Regulatory Economics, Vol 5. 233-249

Charles, A., Darne, O., Fouilloux, J. 2013. Market efficiency in the European carbon markets. Energy Policy, Vol 60. 785-792

Chevallier, J. 2010. Modelling risk premia in CO2 allowances spot and future prices. Economic Modelling, Vol 27, Issue 3. 717-729

Chevallier, J. 2009. Carbon futures and macroeconomic risk factors: A view from the EU ETS. Energy Economics, Vol 31, Issue 4. 614-625

Dales, J., H. 2002. Pollution, Property and & Prices. An essay in policy-making and economics. New Series in Environmental Economics. 127 pages.

Daskalakis, G. 2013. On the efficiency of the European carbon market: New evidence from Phase II. Energy Policy, Vol 54. 369-376

Daslakis, G., Psychoyios, D., Markellos, R. N. 2009. Modeling CO2 emission allowance prices and derivatives: Evidence from the European trading scheme. Journal of Banking & Finance, Vol 33, No. 7. 1230-1241

Dickey, D., A, Fuller W., A. 1979. Distribution of the estimators for Autoregressive Time Series with a Unit root. Journal of the American Statistical Association. Vol 74, Issue 366. 427-431

Engle, R., F., Granger, C., W., J. 1981. Co-Integration and Error Correction: Representation, Estimation, and Testing. Econometrica. Vol 55. 251-276

Ellerman, A. D., Convery, F. J. 2010. Pricing Carbon: The European Union Emissions Trading Scheme. Cambridge University Press. New York. 365 pages.

European Union. 2003. Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003. Establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC. Official Journal of the European Union, L 275/32. 32 – 46

European Union. 2008. Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008. Amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas ©emission allowance trading within the Community. Official Journal of the European Union, L 8/3. 3 - 21

European Union Publications Office. 2013. The EU Emissions Trading System (EU ETS) Fact sheet. Accessed 30 May 2014. Available: http://ec.europa.eu/clima/publications/docs/factsheet_ets_en.pdf

Fama, E.F. and French, K.R., 1987. Commodity futures prices: Some evidence on forecast power premiums, and the theory of storage. Journal of Business, Vol 60, Issue 1, 55-73

Gorton, G.,B., Hayashi, F., Rouwenhorst, K.G. 2012. The Fundamentals of Commodity Futures Returns. Review of Finance 2012. First published online August 9, 2012. Oxford Journals

Goulder, L., Schein, A., R. 2013. Carbon Taxes Versus Cap and Trade: A Critical Review. Climate Change Economics. Vol 4, No. 3. 28 pages.

Harrison, D., Sorrel, S., Radov, D., Klevnas, P., Foss, A. 2005. Interactions of the EU ETS with Green and White certificate Schemes: Summary Report for Policy Makers. Nera Economic Consulting

Hicks, J., R. 1939. Value and Capital. Second edition. Oxford University Press. Cambridge

Hull, J., C. 2012. Risk Management and Financial Institutions. Third Edition. Wiley Finance.

Johansen, S. 1988. Statistical Analysis of Cointegration Vectors. Journal of Economic Dynamics and Control. Vol 12. 231-254

Keynes, J., M., 1930. A Treatise on Money. Vol 2. Macmillan. London

Kremser, T., Rammerstorfer, M. 2010. Convenience yield and risk premium – Comparison of the European and US natural gas markets. Article. Vienna University of Economics and Business. 43 pages.

Madaleno, M., Pinho, C. 2011. Risk Premia in CO2 allowances: spot and futures prices in the EEX market. Management of Environmental Quality: An International Journal. Vol 22, Issue 5. 550-565

McKinsey & Company. 2010. Impact of the financial crisis on carbon economics. Version 2.1 of the Global Greenhouse Gas Abatement Cost Curve. 12 pages

Mizrach, B. 2011. Integration of the global carbon markets. Energy Economics, Vol 34, Issue 1. 335-349

Modigliani, F., Miller, H. M. 1958. The Cost of Capital, Corporation Finance and the Theory of Investment. The American Economic Review, Vol. 48, No. 3. 261-297

Nance, D.R, Smith, C.,W., Smithson, C.,W. 1993. On the determinants of Corporate Hedging. The Journal of Finance. Vol 48, No. 1. 268-284

Nazifi F. 2013. Modelling the price spread between EUA and CER carbon prices. Energy Policy. Vol 56. 434-445

NZ Ministry for the Environment. The New Zealand Emissions Trading Scheme Information. Accessed 20 July 2014. Available at: https://www.climatechange.govt.nz/emissions-trading-scheme/

Pindyck, R., S. 2011. Microeconomics. Eight Edition. The Pearson Series in Economics.

Pindyck, R., S. 2001. The Dynamics of Commodity Spot and Futures Markets: A Primer. The Energy Journal, Vol 22, Issue 3. 1-29

Schwartz, G. 1978. Estimating the dimension of a model. The Annual of Statistics. Vol 6. No 2. 461-464.

Svensson, L. E. 1994. Estimating and Interpreting Forward Interest Rates: Sweden 1992-1994. Working paper No 4871. National Bureau of Economic Research. Cambridge, MA

Talberg, A., Swoboda, K. 2013. Emissions trading schemes around the world. Department of Parliamentary Services. 27 pages

Taylor, F. 2010. Mastering Derivatives Markets: A Step-by-Step Guide to the Products, Applications and Risks. Fourth Edition. Financial Times, Prentice Hall.

Trück, S., Wolfgang, H., Weron, R. 2012. The Relationship between Spot and Futures CO2 Emission Allowance Prices in the EU ETS. HSC Research Report 12 / 02. Wroclaw University of Technology. 26 pages.

Wall, L., D., Pringle, J., J. 1989. Alternative Explanations of Interest Rate Swaps: A Theoretical and Empirical Analysis. The Journal of the Financial Management Association Summer89. Vol 18, Issue 2. 59-73

Walsh, B. 2013. Time. Vol 181. Issue 4. 1-4

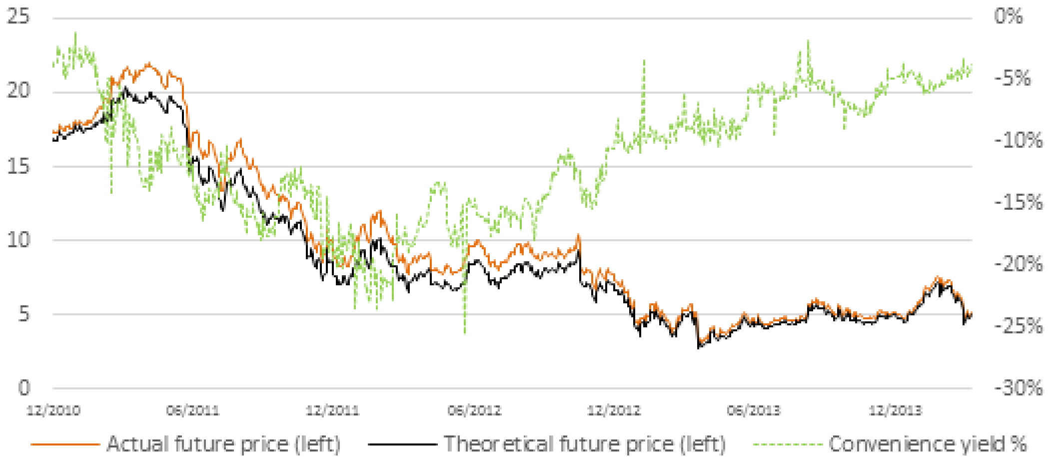
Weron, R. 2008. Market price of risk implied by Asian-style electricity options and futures. Energy Economics. Vol 30, Issue 3. 1098-1115

Wolfe, J., N. 1968. Value Capital and Growth. Transaction Publishers. 552 pages.

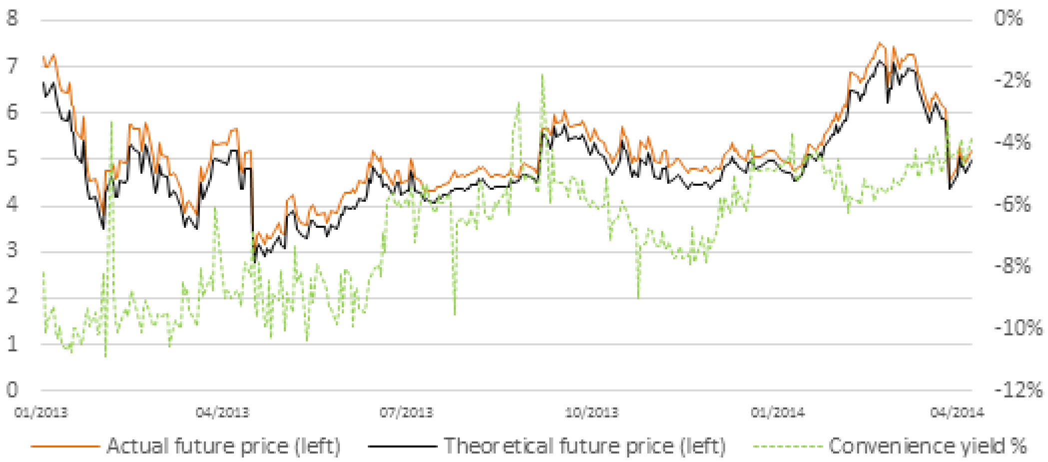
APPENDICES

Appendix 1. Theoretical vs. actual future prices and convenience yield

Dec-15 – Cross-phase

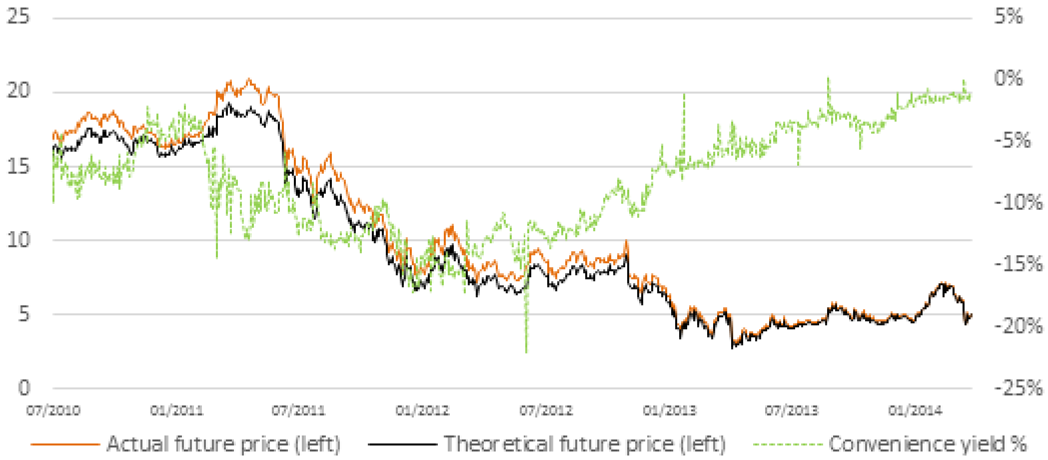


Dec-15 – Phase 3 only



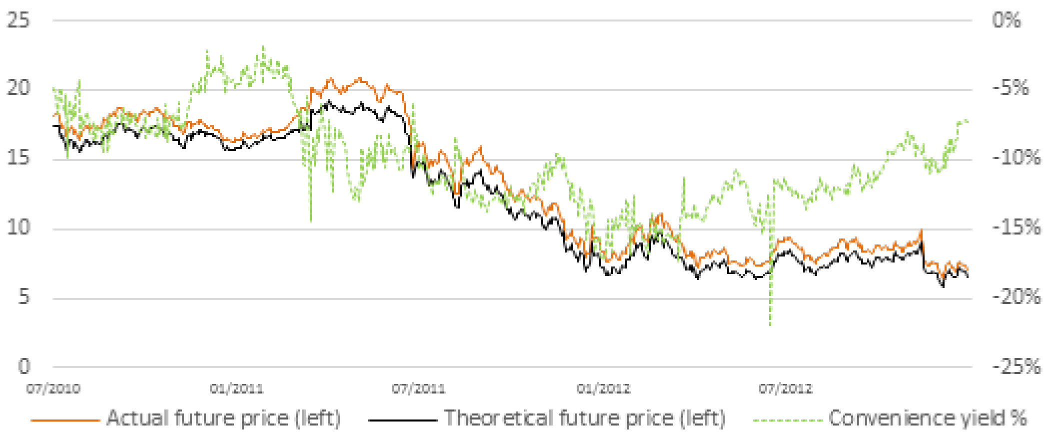
Dec-15 – Phase 2 only

Dec-14 – Cross-phase

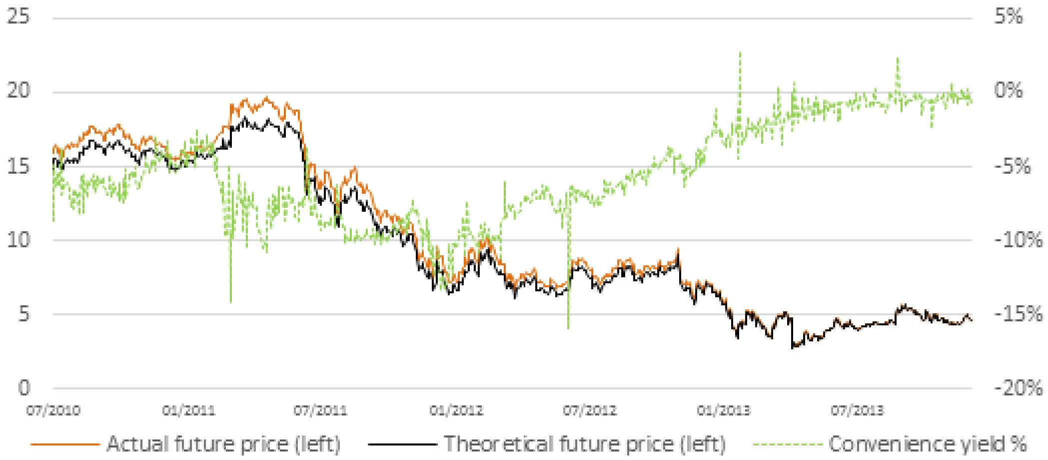


Dec-14 – Phase 3 only

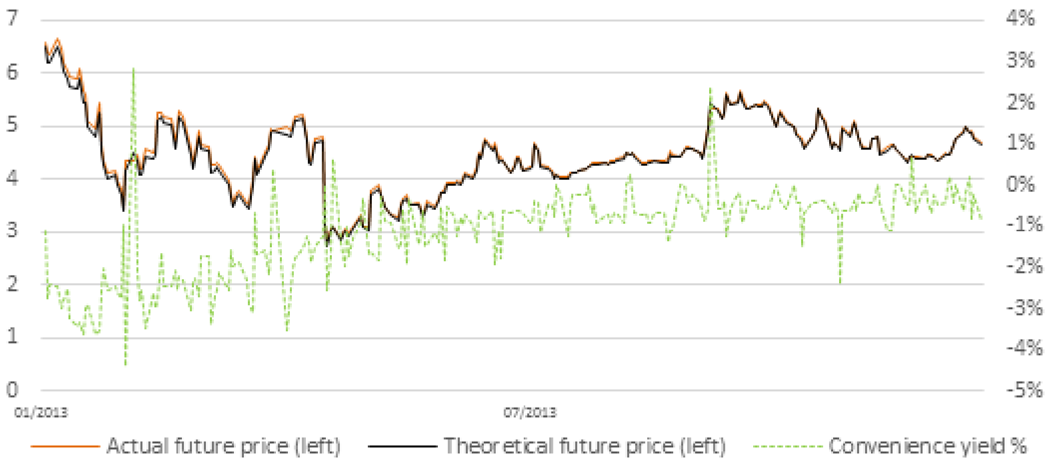
Dec-14 – Phase 2 only



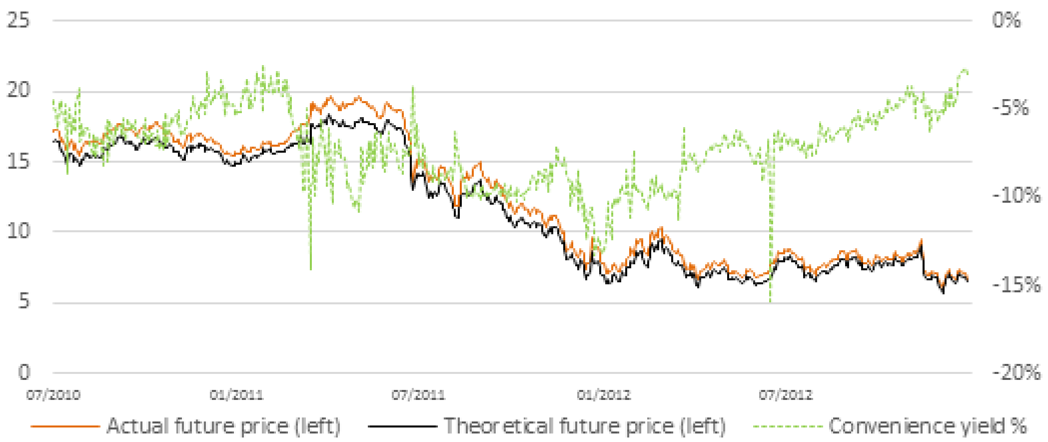
Dec-13 – Cross-phase



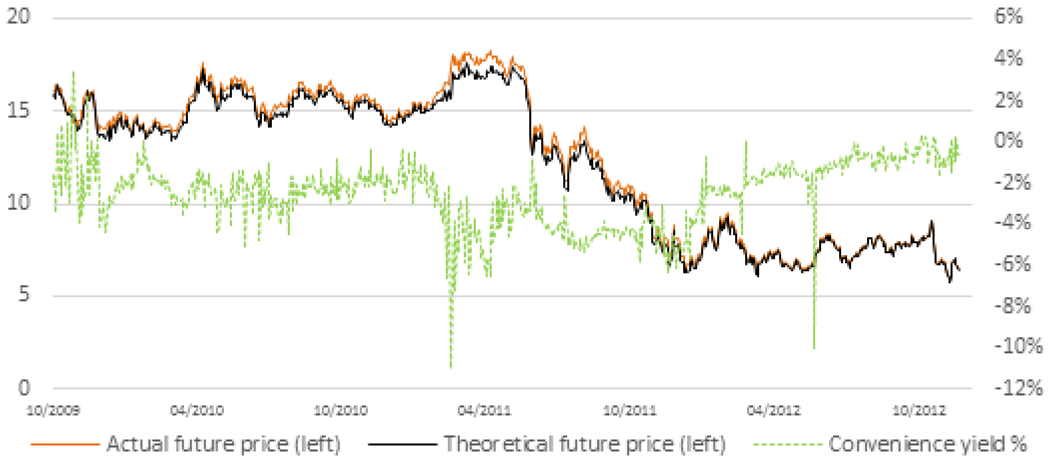
Dec-13 – Phase 3 only



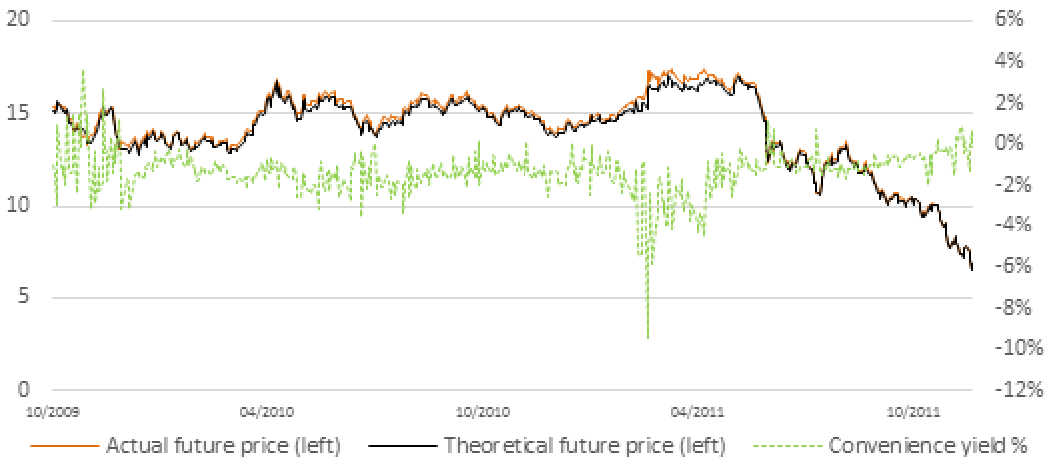
Dec-13 – Phase 2 only



Dec-12 – Phase 2 only



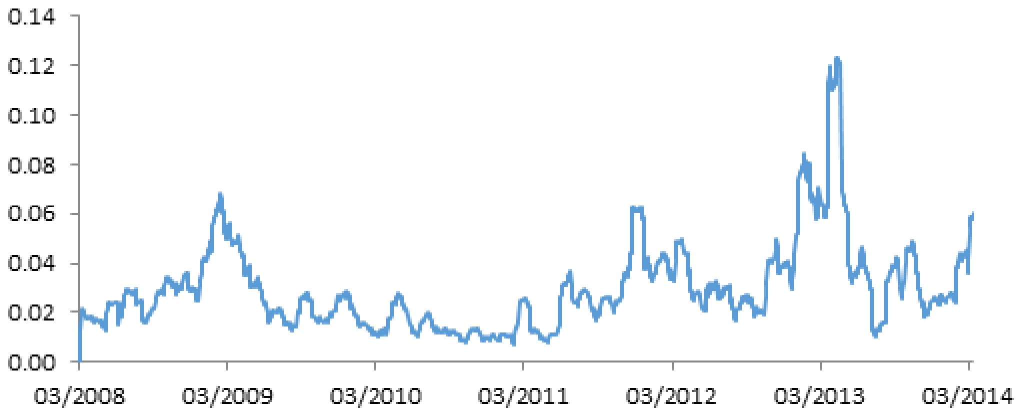
Dec-11 – Phase 2 only



Dec-11 – Phase 2 only

Appendix 2. Historical daily volatilities

20 days historical spot price volatility



40 days historical spot price volatility