Carbon Risk in the Light of the Changing EU ETS

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ABSTRACT

The establishment of the EU emission trading scheme (EU ETS) has internalised climate change risk into carbon risk, to which companies are becoming increasingly exposed. Understanding the market is essential for good risk management. However, the many uncertainties present in the market are difficult to grasp and make it hard to quantify the risk. The main purpose of this thesis is to gauge the factors affecting the market participants' carbon risk exposure and provide insight for hedging the carbon risk in Phase II and III of the EU ETS.

The first part of this study analyses different uncertainties and scenarios in the carbon market and evaluates their impact for the future development. Special attention is given to institutional factors as the most relevant risk drivers in the mid-term perspective. In the second part, the cost-of-carry model is tested together with cointegration analysis between the European Union Allowances (EUA) and Certified Emission Reduction (CER) spot and futures prices, futures being the most liquid hedging instrument. The results here are mixed. While no cointegration can be proved with certainty in the case of EUA, the CER spot and futures are clearly cointegrated, although definitely not through a cost-of-carry relationship

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Abbreviations and Significant Terms

Annex I countries – Industrialised countries that have agreed to reduce their greenhouse gas emissions by signing the UNFCCC.

Annex II countries – Developed countries responsible for bearing the costs of climate change mitigation in developing countries. Subset of Annex I countries.

Annex B countries – Countries that have ratified the Kyoto Protocol and have committed to reduce their greenhouse gas emissions by a certain percentage (compared to their 1990 levels) by the end of the period 2008-2012.

AAU – Assigned Amount Units, which are emission permits assigned to countries under the Kyoto Protocol. These can be traded between countries, and are also used to offset issued project credits.

Bankability – Possibility to transfer allowances and project credits from one period to another.

CER – Certified Emission Reductions, which are emission permits obtained from the CDM projects, each allowing emission of 1 tonne carbon dioxide equivalents.

ERU – Emission Reduction Units, which are emission permits obtained from the JI projects, each allowing emission of 1 tonne of carbon dioxide equivalents.

EUA – emission permit issued and traded within the EU ETS, each allowing emission of 1 tonne of carbon dioxide equivalents.

Installation – a single emitting entity such as a factory or a power plant.

UNFCCC – The United Nations Framework Convention on Climate Change.

Introduction

The first mandatory carbon emission market – the European Union Emission Trading Scheme (EU ETS) – was implemented in 2005 to fulfil the goals set in the Kyoto Protocol in 1997 to reduce the emissions of greenhouse gases in Europe. Target for EU-15 is an average reduction of CO_2 emissions of 8% between 2008 and 2012 compared to the 1990 base year level (EEA 2008). Moreover, the EU has taken a leading role in mitigating carbon emissions and has further set a goal of a 20% reduction compared to the 1990 level by 2020 in EU-27, or even 30% provided that a satisfactory global agreement is achieved in the post-Kyoto period. One effect of this policy is the rise of a so-called carbon risk due to the uncertain future costs of CO_2 emissions for companies.

The European energy and industrial companies with “installations”, i.e. production units included in the EU ETS, are experiencing increasing carbon risk exposure and uncertainties related to the development of the carbon markets, which definitely creates a need for careful risk assessment and actions to be taken accordingly.

Emission trading in the EU is organized into three phases, the first in 2005-2007 (Phase I), the second 2008-2012 (Phase II) and the third 2013-2020 (Phase III), with to some extent varying rules. Currently, sectors obliged to cover their emission with permits under the EU ETS are energy activities, production and processing of ferrous metals, and the mineral and pulp and paper industries (Annex I, 2003/87/EC). However, several emission-intensive sectors are going to be added to the scheme.

While the first phase was characterised by generous grandfathering (free allocation) of most permits to most installations, the total amount of allocated permits during the second period is lower and more uneven among installations. One extreme example is the Swedish energy sector, which did not receive any grandfathered permits, meaning that it has to buy all permits in the market. Although somewhat uncertain, the plan is to auction off a large share of permits in the third phase. Utilities are the most affected as they are the number one source of emissions, almost 40% in the EU (EEA 2009) and as they are not directly exposed to international competition; they do not receive the same political support for protection as the energy-intensive industry.

Due to the emergence of regulation of carbon emissions also in other parts of the world (e.g. in the US and Australia), carbon risk will become important for an increasing number of companies. It can be noted though that some companies already pay to some extent for their emissions, mostly through voluntary emission trading schemes as a result of their corporate social responsibility policies.

From an efficiency point of view, it is important that the continuation of a trading scheme is guaranteed. However, there are many uncertainties, both about the design of the EU ETS and the global market, which are largely dependent on the 15th Conference of the Parties (COP15) to the Kyoto Protocol in Copenhagen in December 2009.

Take, for example, a production portfolio of an electricity producer. Being long in electricity and short in emission allowances (and often other production inputs) can, according to the portfolio theory, be preferable to a fully hedged position in carbon – at least to some point before the reporting date. However, high volatilities and recent unstable correlations between these commodities imply that there might be a necessity for different kind of hedging strategies.

The purpose of this study is to analyse the EU emission trading scheme and provide insight for carbon risk management in the rest of Phase II and Phase III. The EU carbon market is still relatively young, which limits the quantitative studies and their interpretation. Moreover, there are considerable changes expected in the market. This paper therefore will evaluate the sources of uncertainty in the EU ETS and examine the relationship between the emission permits' spot and futures prices in order to give some insight into how good of a hedge the most liquidly traded instruments really provide.

The paper is structured as follows: the first part gives a brief overview of the market; the second part brings out the most important risk factors in the 'foreseeable future' of the carbon market, and the third part tests the cost-of-carry model and the cointegration between spots and futures in the European Union Allowances (EUA) and the Certified Emission Reductions (CER) markets.

1. Carbon Market Background

The EU ETS or the EU domestic emission trading scheme is closely related to the other mechanisms created under the Kyoto Protocol. The relationships are explained in Table 1.

	Kyoto Protocol				
		Project Based Mechanisms		Emission Trading	
	LULUCF	**CDM**	**JI**	**Domestic**	**International**
Programs / Basic assumptions	Land Use, Land Use Change and Forestry (LULUCF)	Clean Development Mechanism (CDM)	Joint Implementation (JI)	Example: European Union Emission Trading Scheme (EU ETS)	International
Securities	**RMU**	**CER**	**ERU**	**EUA**	**AAU**
Explanation of the acronym	Removal Unit	Certified Emission Reduction	Emission Reduction Unit	European Union Allowances	Assigned Amount Unit
Responsible body	Government of the host country	CDM Executive Board	Government of the host country	Governments of the EU member states	Governments of countries that have ratified the Protocol
Conditions for issuing	Net removals by sinks from the land use, land use change and forestry sector. Afforestation, reforestation and deforestation activities.	Investing in a project in a country that does not have any commitments towards the Protocol i.e. a developing country.	Investing in a project in another Annex I country (Kyoto compliant), other than the country of origin. Usually economies in transition. ERUs issued from the host countries' AAU reserve.	In Phase I and II according to National Allocation Plans (taking into account targets set in the Kyoto Protocol). In Phase III EU wide emission gap.	According to the cap set for the installations in countries that have ratified the Protocol.
		Traded in (at least some phases of) EU ETS			

Table 1

Overview of the Kyoto Protocol and Flexible Mechanisms (compiled based on UNFCCC, 2009; EEA, 2008; and Labatt and White, 2007)

All carbon emission permits are commodities by nature. The variation in spot prices and daily returns are illustrated in Appendices 1 and 2, with the annualised volatility of daily returns being 58% in Phase II (for comparison, the number for FTSE Europe is 37% and for the daily average prices of electricity on NordPool it is 101%).

Worldwide, the carbon markets are rapidly developing – the volume increased 1.7 times from 2006 to 2007. In 2007, allowance markets accounted for 70.7% by volume (78.7% by value) of the total carbon markets, with the EU ETS being the largest of these both by volume and value with 97.7% and 99.4%, respectively. The rest of the transactions were made on project-based markets, with Clean Development Mechanism (CDM) being by far the largest. (Capoor and Ambrosi 2008)

Up until 2012 (in the 2^{nd} phase), the largest source of emission allowances will be the free allocations specified in the National Allocations Plans submitted by the member states to the European Commission. The surpluses or shortages of EUAs can be traded on the secondary market. Alternatively, credits from project-flexible mechanisms can be used. However, mandated installations included in the EU ETS cannot surrender for compliance more than 1400 million CERs and Emission Reduction Units (ERUs) or 13.4% of the total number of allowances during Phase II (Capoor and Ambrosi 2008). The project-based credits can, in addition to being directly invested in CDM and Joint Implementation (JI) projects in other countries, also be purchased on exchanges.

After 2012, the markets will (according to the proposals by the Commission) function in essentially the same way, except for that a large part of the EU allowances will be auctioned off to the companies. The electricity sector will be the one most affected by this, since these companies will have to pay for all of their emissions. However, for all companies in the trading system, there is an opportunity cost of the emission permits although it may vary depending on the allocation rules (see Hjalmarsson 2008).

In order to proceed with estimating the factors influencing the carbon exposure for the companies under the EU ETS it is necessary to point out different options that can be used to meet the compliance requirements. In principle, the companies have three options: abate their emissions, invest in less carbon-intensive production facilities or use carbon emission permits to offset the emitted CO_2.

This paper deals with the development and risks associated with the third option and consider the first two only to the extent necessary to gauge the impact on supply and demand in the trading scheme.

2. Factors Driving the Carbon Market

At present, there are many uncertainties related both to the development of the EU ETS and to the other regional or country-based emission trading schemes and their links to the former. Some of these contingencies will be resolved via negotiations in December 2009; others further in the future. This chapter qualitatively discusses risk exposure related to the movements in the CO_2 price.

2.1 Supply and Demand

One of the most fundamental factors is the cap set for the scheme, or the supply of allowances. Setting an accurate cap is important for the efficiency of the system by establishing a price for emitting that creates incentives for emission reductions at about the same marginal cost as the marginal abatement costs in the economy outside the trading system, while at the same time meeting the Kyoto objective. The subsections that follow evaluate the most relevant factors for the supply-demand balance.

2.1.1 Market Fundamentals

Since the electricity sector is the biggest consumer of EUAs, there is an interrelationship between European electricity prices and permit prices. As shown in Appendix 4, there is a strong correlation between different emission intensive energy commodities and EUA. Mansanet Bataller et al. (2006) found that temperature can also somewhat explain EUA returns – but only when there are extreme weather conditions. The increasing use of renewable energy (e.g. wind, hydro and tidal energy) in Europe will probably increase the impact of weather. For example, low temperatures will increase the consumption of heat and electricity produced from emission-intensive resources. Especially wind power with stochastic supply will increase the demand for regulation (back-up) capacity, which, if not enough hydro power is available, will be supplied by thermal power.

The relationship between energy commodity prices and carbon prices is rather intuitive. Firstly, again, coal, gas and oil are inputs in the electricity production. Secondly, oil prices are related to the economic cycles, which are directly linked to the output of the industrial companies under the EU ETS and their demand for emission allowances.

2.1.2 Market Sentiment

The perception and expectations about the supply-demand balance, and consequently the price, can vary remarkably between the market participants and deviate from the efficient price or actual spot prices. This is more important perhaps in the context of Phase II, as it is predictable only in the shorter term and related to the fact that the market is still relatively immature. The past has shown that risk aversion and herd behaviour can cause wide price swings in the market. The power and heat sectors were short of allowances in Phase I, while the overallocation in iron and steel and in cement were roughly 24% and 7%, respectively (Antes et al. 2008). Nevertheless, industrial companies, being risk averse, were reluctant to sell in the beginning of the phase, which resulted in relatively high price levels (Schieldrop 2009). Then, in Phase II, it was the industrial companies that supplied the market with permits, due to their liquidity problems (*ibid.*), although their reserves were not as abundant as they had been previously.

Yet, Daskalakis and Markellos (2008) argue that it is the power producers who have the upper hand in the market. Firstly, they are in a better position to more accurately calculate the overall market position and therefore to exploit any potential inefficiency and, secondly, exert market power either individually or through tacit collusion and can therefore manipulate the market.

2.1.3 Changes in Technology and Production

Abatement possibilities through production changes can be divided into short-term and long-term options. In the shorter term, fuel switching, which is mainly used to mean changing from coal to natural gas, is used to minimise production costs. However, since it is not possible to cover all the energy needs in Europe with gas, other abatement and emission reduction opportunities should be considered.

Renewable Energy

The climate-energy legislative package, adopted by the European Council on 6 April 2009, sets a target of a 20% share of energy from renewable sources in the EU's final consumption of energy (up from about 9% today) and a 10% share of energy from renewable sources in each member state's transport energy consumption by 2020. Direct investment subsidies, Feed-in Tariffs and Green Certificate Markets have been set up by individual member states to promote this development. In addition to reducing the impacts on the climate, incentives for promoting the use of renewables have emerged also with reference to energy supply security. To what extent improved energy security is achieved and whether it is worth the high cost and subsidies linked to renewables is an open question

As previously mentioned, renewables are more weather dependent, making the supply of electricity more unpredictable. For example, in the case of low wind or precipitation levels, producers need to switch to fossil fuels. In spite of having a decreasing effect on the demand for allowances in the long term, they do increase the price volatility of the allowances.

Nuclear Energy

Nuclear energy, being carbon emission free, is becoming increasingly appealing in the light of the expected allowance deficit and price hikes. After having long been a politically less attractive option, there has been an emerging interest in nuclear power in several countries since the turn of the century. Other favouring factors include increasing energy demand, security of supply, and relative cost effectiveness. Since most of the increase in nuclear capacity (over 80%) is expected to occur in developed countries that already use nuclear power (WNA 2007), the demand for permits will be affected significantly. On the other hand, long building cycles and a lack of necessary legislation in some countries will limit the use of nuclear energy in the near future. Working in the opposite direction, i.e. increasing demand for emission permits, would be a decommissioning of nuclear power in Germany. If it is realised, most nuclear power production will probably be substituted by natural gas from Russia (through the politically controversial Nord Stream pipeline in the Baltic Sea) increasing annual emissions by 40-50 Mton CO_2 (this may be compared to the present German allocation quota of about 500 Mton or the Swedish allocation quota of about 22 Mton per year) (Hjalmarsson 2009).

Carbon Capture and Storage

Carbon capture and storage (CCS) gives great hope for a carbon free technology. In September 2008, Vattenfall opened its first power plant to incorporate CCS at Schwarze Pumpe in Germany (Economist 2009) and CCS operations at the Sleipner offshore platforms in the North Sea began already in 1996 (Cappelen and Corrigan 2008). Hence, the technology for implementing this kind of abatement is available, though the long-term prospects are still uncertain. The biggest hurdle is commercial viability – it is by far the most expensive form of abatement, and hence requires sufficiently high and stable allowance prices to penetrate the market. Although, the EU has decided to support up to 12 CCS demonstration projects from the new entrant reserve in Phase III (COD(2008)0013), widespread use of CCS is not expected to be realised until after Phase III.

2.1.4 Interaction Between Different Flexible Mechanisms

One of the sources affecting the supply-demand balance at least in the Kyoto period (2008-2012) is the trading of Assigned Amount Units (AAUs) between governments; see Table 1. According to Article 17 of the Kyoto Protocol, countries with AAU surpluses can sell them to countries with deficits. The demand from 2008 to 2012 will be driven primarily by the Japanese and the EU-15 governments (Ramming 2008), while Russia, the Ukraine and Poland have the largest surpluses (EBRD 2009). These kinds of excessive government purchases of AAUs imply that the demand for project certificates (CER and ERU) will decline, leading to a decrease in their prices and also in EUA price. However, the impact on the EUA price would probably be somewhat smaller due to limits on using the project credits in the EU ETS. The requirement of ‘greening’ of AAUs imposed on the sellers by buyers and existence of Green Investment Schemes will ensure that proceeds from such trades are used to further mitigate greenhouse gas (GHG) emissions or to support other environmental activities (GIS Manual, 2009). This will probably not allow the countries to close their entire Kyoto gaps (the difference between the target specified in the Kyoto Protocol and actual emissions) with AAUs. However, as Ramming (2008) also mentions, this scenario would be more likely if there were no future global climate agreement.

CDM, as an alternative to AAU's, can also affect the prices within the EU ETS, as the CERs (and also ERUs) are accepted as emission offsets in the EU ETS. Previously, the projects invested in, that have been expected to yield CERs, have in many cases been delayed due to overload at the CDM registry (Capoor and Ambrosi 2008), also directly affecting the demand from the private sector. Moreover, there are other risks associated with participating in a CDM project or purchasing primary CERs (i.e. permits that are not yet officially issued), such as counterparty, carbon regulatory, country, technology performance, business interruption and other risks (Labatt and White 2007), which may jeopardise the arrival of the permits.

2.2 Institutional aspects

The EUA market in Phase II is more sensitive to changes in demand, as the rules and allocations have been already set. For Phase III, though, many uncertainties still persist, which will be largely decided upon by the middle of 2010. The most relevant risk factors are highlighted below.

2.2.1 Auctioning Mechanism

Moving to auction-based allocation rule rather than just distributing allowances for free has two major advantages. Firstly, an auction can raise revenue that can substitute for other taxes, thereby lowering the social cost of new regulation (Goulder et al. 1999, in Åhman et al. 2007), and secondly, in regulated markets, an auction tends to reduce the difference between price and marginal cost, again providing potential cost savings (Burtraw et al. 2001; Parry, 2005, in Åhman et al. 2007). In Phase III, 88% of the allowances for auctioning will be distributed to Member States on the basis of their emissions in the period of 2005-2007 (EU 2009).

Using auctions to allocate allowances has important implications for the secondary market, especially in the light of a rigid cap. Since the positions will be covered from the auctions, the secondary market could become fairly thin (Benz et al. *2008*), unless the market will attract speculators. If not very liquid, market price might not reflect the efficient price of the allowances.

Therefore, the design of the auctioning system is important, as it will play a role in the price discovery in the market. There are, however, still considerable uncertainties left in the market regarding the rules of auctioning in Phase III, which the European Commission has promised to clarify only by 30 June 2010 (EU 2009).

2.2.2 Additional GHGs and sectors added to the EU ETS

Aviation and Maritime Emissions

The aviation industry, which accounts for 1.9-2.4% of global emissions (Committee on Climate Change 2009), will be included in the EU ETS in 2012 (2008/101/EC). However, the companies will have their own permits – AEUAs – although they will also be allowed to purchase from the EUA market. Though the aviation industry will most likely be short in allowances, this will probably not affect the price of EUA significantly. Preparations to also include the shipping industry have started as well (COM(2008)0017). Shipping represents about 4.5% of total global GHG emissions based on 2007 data, but is currently outside the United Nations Framework Convention on Climate Change (UNFCCC) (Warris and Lightburn, 2008).

Additional Greenhouse Gases Included

The climate-energy legislative package regulates additional (1) industries (petrochemicals, ammonia and aluminium) and (2) greenhouse gases (nitrous oxide from nitric, adipic, and glyoxylic acid production facilities and perfluorocarbons from the aluminium industry).

According to EU-wide rules, these industries will receive allowances mostly free of charge, in the same way as industries that are already covered. Gauging the impact of this is extremely difficult, however. If anything, these industries will probably be net long rather than short as they could be subject to carbon leakage.

The capture, transport and geological storage of all greenhouse gas emissions will also be covered in Phase III (see section 2.1.3).

Including additional sectors (such as maritime) later to the scheme will probably increase the price of allowances, as adjusting the supply side is not a recommended action (to guarantee the reliability of the system), which in itself does not mean that it will not be used. While the cap, or reductions of a 20% of emissions, in case of no-agreement scenario is already written into legislation, in case of a satisfactory global agreement (with reductions of 30%) the supply of permits can still be adjusted to some extent by the amount of project credits allowed into the system, depending on the course of negotiations.

2.2.3 Linking

Enlargement of the market can occur in two ways: through global harmonisation of the market and by linking to other systems. In mid term, linking is more feasible. Linking refers to any use of credits or allowances from outside the system for compliance i.e. the use of anything other than the system's own allowances (Ellerman and Joskow 2008). Thus, it covers both the project flexible mechanisms as well as linking different schemes to the EU ETS.

Linking to Flexible Mechanisms

The EU Commission has stated in COM(2008)16 that the limit on project credits in Phase III will remain the same as in Phase II unless a satisfactory international agreement is reached in December 2009. If an agreement is reached, then reduction in emissions by 30% (instead of 20%) will increase the need for additional CERs and ERUs making it possible to increase the quota without undermining the EU objective to increase the use of renewable energy.

Linking to Other Emission Trading Schemes

The expectations in this regard are foremost related to three large developed federal states: the United States, Australia and Canada (and also their regional initiatives). However, there are several possible impediments to linking: when targets, proportion of free allocations and the market infrastructure differ between the schemes, then (a) division of reduction cost can become unfair (Rix and Paul 2008), and (b) it can be difficult to reach individual targets (also in terms of the EU renewable energy policy, for example). On the other hand, there are benefits from linking, such as a potentially lower aggregate cost of reducing greenhouse gas emissions, increased liquidity and reduced price volatility (COD(2008)0013), which do seem appealing to EU authorities.

However, linking requires some extent of harmonising, especially in banking, allocation rules, monitoring-reporting and emission targets (Zaman 2005). Moreover, there is another necessary condition that has to be satisfied – existence of other mandatory cap and trade schemes. For example, while ten US states have already set up their scheme (the Regional Greenhouse Gas Initiative) (RGGI 2009), the federal government has been rather cautious on this issue. The EU readiness for linking is also shown in the fact that a clause was added to the adopted climate-energy package allowing not only linking between independent states but also regional carbon emission exchanges. Any kind of linking would be desirable from a private sector perspective as the main impact would almost certainly be lower costs.

3. The Futures Market

It is evident from the previous discussion that the carbon price volatility and the unpredictable developments in the market create a necessity to hedge the risk. Since futures are the most liquid and accessible instruments to date, it is important to assess whether the futures market offers effective hedging opportunities i.e. whether futures and the underlying assets follow the same trend or process, which is especially important from a portfolio management perspective. In addition, this chapter will discuss the pricing issues. First, the cost-of-carry model is used on EUA in order to determine the existence of convenience yields and to provide an introduction for the subsection that follows: Cointegration between spot and futures, performed both on EUA and CER.

3.1 Theory and Previous Research

3.1.1 The Cost-of-Carry Model and Convenience Yields

Commodities are generally divided into two subgroups: investment assets (e.g. gold and silver) and consumption assets (e.g. oil). The difference is that the latter is used in a production process, which usually makes it more desirable to hold a long position in the spot in order to meet unexpected demand shocks or to profit from local shortages. (Hull 2000)

The cost-of-carry model thus posits that the futures price should equal the spot price, adjusted for the opportunity cost of holding a spot position (Milunovich and Joyeux 2007). Hence, the no-arbitrage assumption, adjusted to the short-selling constraints for a consumption commodity, stipulates the following relationship between futures and spot prices:

$$F_{t,T} = S_t e^{(r+u-y)(T-t)} \qquad (1)$$

where, S_t is the spot price, T-t is time to maturity and r is the risk free interest rate. Specific for commodities are storage cost, u, and convenience yield, y. The latter is the benefit from holding the consumption assets.

Since emission allowances do not physically exist and are stored in the Community International Transaction Log, no significant storage or inventory costs occur from holding the asset except the time value of money which is lost due to the cash held in the permits. Hence, the only possible difference between the spot price and the discounted futures price in case of emission allowances is the (gross) convenience yield.

Uhrig-Homburg and Wagner (2007) also point out that since spot EUAs are only needed once a year to fulfil compliance requirements, then if futures mature before the end of the next compliance date, there is no benefit in holding spot EUAs compared to holding the corresponding long futures position. Thus, the convenience yield one year prior to the expiration of a future should equal 0.

The implied convenience yield (assuming 0 storage costs) is derived from the previous formula, the equation (1):

$$y_t = r_t - \frac{\ln(F_t / S_t)}{(T - t)} \qquad (2)$$

Several studies on other markets have shown that there exists a relationship between the convenience yield and some exogenously given variables, such as the inventory stock (e.g. Heaney 2002). In this case, the convenience yield itself may be stochastic and, if so, will weaken the link between the spot and futures prices (Uhrig-Homburg and Wagner 2007).

Previous research on the cost-of-carry model, based on EUA Phase I data, has revealed mixed results. Daskalakis, Psychoyios and Markellos (2009), based only on the mean squared error, found that futures prices for the Phase I futures evolved according to the cost of carry model with no significant convenience yields. Further, Uhrig-Homburg and Wagner (2007) claimed the same, for the period after December 2005, using cointegration analysis. In contrast Milunovich and Joyeux (2007) rejected the cost-of-carry approach for all futures traded in Phase I by also using cointegration analysis, claiming that violation of the cost-of-carry relation can be interpreted as an indicator of market inefficiency and pointing to arbitrage opportunities in the market.

3.1.2 Cointegration between Spot and Futures Prices

Rewriting the cost-of-carry model in (1), it is easy to see that according to the theory there must be one-to-one linear relationships between the natural logarithmic values of spot and futures prices:

$$\ln F_t = \ln S_t + r_t(T-t) - y_t(T-t) \qquad (3)$$

Thus, in the case of sufficiently stable convenience yield and interest rate values (or, alternatively, including them) cointegration analysis can be used to shed light on the long-run relationship between the variables.

Although risk management techniques are largely based on correlation, these can be highly volatile and do not give an adequate picture in the long term of the actual relationship between asset prices. This can be complemented by cointegration analysis, which attempts to identify common driving factors in stochastically trending data, thus identifying long-run equilibrium relationships between economic variables (Hjalmarsson and Österholm 2007). From a risk management point of view, it is important that there exists a relationship between spot and futures – in order for futures to be an effective hedging instrument. Moreover, cointegration analysis could provide insight into questions regarding which asset reacts first to the exogenous shocks and how quickly prices converge to the mean-reverting equilibrium level.

A necessary condition for testing cointegration between two or more variables is that the variables are integrated at least at the order of one, I(1), meaning that taking the respective number of differences (at least one) would make the series stationary. When this is satisfied, a vector error correction model (VECM), proposed by Engle and Granger (1987), can be fitted in order to test short term dynamics and causality in the relationship. The simplest, bivariate model, in the case of spot and futures prices can be expressed as:

$$\Delta \ln S_t = \alpha_0 + \sum_{i=1}^{m} \alpha_{1i} \Delta \ln F_{t-i} + \sum_{i=1}^{n} \alpha_{2i} \Delta \ln S_{t-i} + \alpha_3 u_{t-1} + \varepsilon_1 \qquad (4)$$

$$\Delta \ln F_t = \beta_0 + \sum_{i=1}^{k} \beta_{1i} \Delta \ln F_{t-i} + \sum_{i=1}^{p} \beta_{2i} \Delta \ln S_{t-i} + \beta_3 u_{t-1} + \varepsilon_2$$

where ΔlnS_t and ΔlnF_t are changes in logarithmic values of spot and futures prices, respectively, and u_{t-1} is the lagged error term from the cointegrating vector, reflecting deviations from the long-term equilibrium relationship (estimated by the ordinary least squares):

$$\ln F_t = \gamma_0 + \gamma_1 \ln S_t + u_t \qquad (5)$$

For more sophisticated analyses or relationships, adding variables to the cointegrating vector and equations with respective variables to the system can augment the test. When studying futures prices, then evidently these variables could be the interest cost and the convenience yield. The latter, even though not observable, can in some cases be modelled. VECM estimates the impact of the lagged error terms and of the lagged first differences of the variables on each of the variables individually. In other words, it estimates whether there exists any lead-lag relationships between the variables.

There are more sophisticated tests developed after Engle and Granger. One of them is the Johansen test, which is used to test the number of cointegrating relationships between certain variables. The Johansen test seeks the linear combination that is most stationary (based on the eigenvalues of a stochastic matrix) whereas the Engle-Granger is based on the minimum variance. (Maddala and Kim 1998)

The studies on cointegration in the EUA market in Phase I are more unanimous than those on the cost-of-carry model, though cointegration testing is usually coupled with the previous concept. The published studies state a link between EUA spot and futures prices, implying that the Phase I futures were suitable instruments for hedging CO_2. Milunovich and Joyeux (2007) show that there was bi-directional Granger causality between the spot and futures prices. In contrast, Uhrig-Homburg and Wagner (2007), studying almost identical time periods, argue that the EUA futures market led the price discovery process. Thus, at least in Phase I, the EUA shared more characteristics with financial assets (in which case it has been proved that futures generally drive the spot market) than with commodities. In addition, lead-lag relationships were present even with daily data, which contradicts the efficient functioning of the market, according to which information should be revealed in the prices contemporaneously.

3.2 Data

The standard futures contracts on European exchanges are annual contracts, since the allowances and offsets are required to be surrendered only once a year by April. All EUA and CER futures listed on NordPool (similarly to EEX and Bluenext) mature every year at the beginning of December, up until 2012. In addition, there are March contracts available on NordPool before the next compliance date.

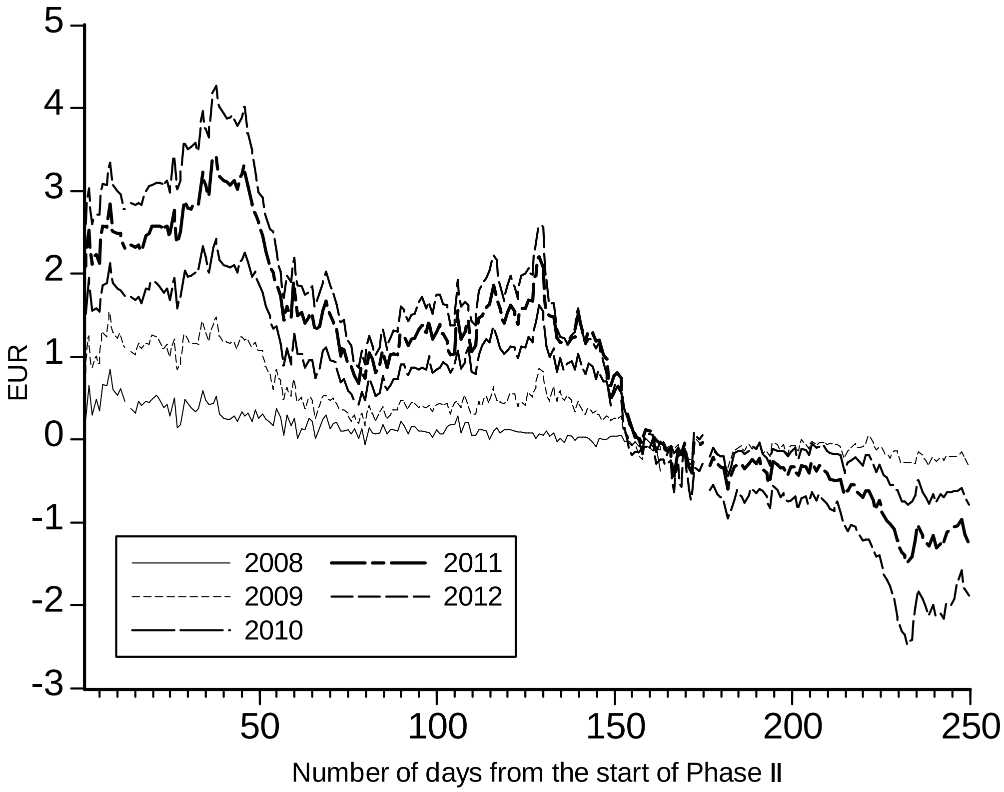
The data used in this paper for the empirical part on EUA, CER futures prices and electricity prices was provided by NordPool. The CER spot price was obtained from the BlueNext exchange through Datastream. All the other time series were also taken from Datastream. Only data from Phase II was examined, since in essence, in Phase I and Phase II, the underlying for the futures – emission allowances – were fundamentally different assets. One EUA granting the right to emit 1 tonne of CO_2 only in Phase I and the other granting the right for Phase II and onwards. The difference is clearly illustrated also by the price series given in Appendix 3. In the case of EUA, the time series runs from 15 April 2008 (start of trading of the spot on NordPool in Phase II) to 15 April 2009. The CER spot price series is available for the period 12 August 2008 to 15 April2009.

All testing was based on daily closing prices. The 12-month Euro Interbank Offered Rate (Euribor) is used as an approximation of the interest rate everywhere, except for the 2008 theoretical futures prices for which the interest rate was interpolated from 11 quoted consecutive Euribor rates starting from 1 week up until 8 months (rates for 1-3 weeks and 1-8 months).

3.3 Empirical Results

3.3.1 The Cost-of-Carry Model and Convenience Yields

At the beginning of Phase II the EUA market was in normal backwardation (expected future prices were above the market prices), which in November 2008 turned into normal contango (opposite of backwardation), as shown in Figure 1.



	2008	2009	2010	2011	2012
MSE[1] (%)	0,0109	0,0600	0,1950	0,4127	0,6996

Figure 1

Differences between theoretical and actual futures prices with maturities in the respective years written on EUA. The theoretical futures were priced according to the cost-of-carry relationship, assuming 0 convenience yields.

However, the differences decreased considerably already in July after the prices started their downward trend in Phase II (see Appendix 1 and 3). The corrections in the market

[1] The Mean Squared Error is calculated as percentage according to the formula:

$$MSE = \frac{100}{N} \sum_{t=1}^{N} \left(\frac{F_t^{Theor} - F_t^{Actual}}{F_t^{Actual}} \right)^2$$

reveal the market participants' perception about the shortage of allowances, which was reduced due to the bleak economic growth anticipation. Further on, it was exacerbated by liquidity problems among companies, which made a futures position more desirable compared to the spot, in the hope of better cash flows matching, i.e. by selling the permits now and buying them back when sales are expected to increase again. The difference between the spot and December 2012 futures has increased more relative to other futures at the end of the studied period, showing some of the market participants' strategy to take advantage of the current underpriced situation and enter into an agreement to buy the EUAs in 2012 in order to transfer these into Phase III, which is expected to have a significant shortage of allowances.

The price of the Dec08 futures did converge to the spot price deviating on average 0.8%. Considering the market microstructure this would probably still be in the no-arbitrage bounds. MSE calculations (provided in Figure 1) further imply the fit to the cost-of-carry model.

As shown in Figure 2, the implied convenience yields appear to have a 'term structure' in the futures market (though coinciding in the second quarter of the observed period), despite moving stochastically in time. The volatility in convenience yields clearly increased after the market turned into normal contango. There are clear downward-sloping convenience 'yield curves' both at the beginning and at the end of the analysed period. While the latter was explained previously (with the liquidity trap), the beginning of the period, when the market was bullish, contradicts the intuitive explanation: the further in time the futures delivery is, the more exposed to market movements one is and the more beneficial from a risk management and arbitrage point of view it should be to hold a spot. Nonetheless, since emission permits are needed for the production process only once a year (for compliance in April) and are bankable, the phenomenon can possibly be explained by the fact that there was much more unawareness about the actual emissions in the first half of the phase. Moreover, it is the first time during the EU ETS that economies are in recession, which could have been already incorporated into the expectations, adding even more to the perceived uncertainties.

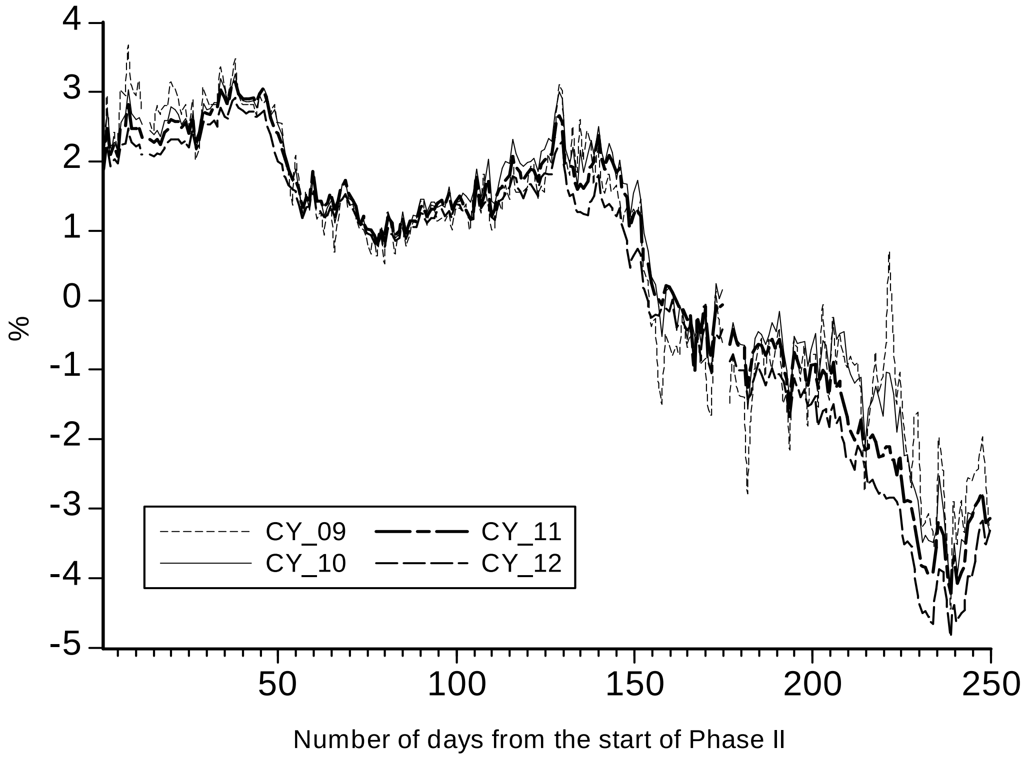


Figure 2

Convenience yields implied from the futures prices maturing in December 2009, 2010, 2011 and 2012 written on EUA.

The convenience yield implied by the 2008 futures should be 0, as the discounted price series should follow the spot price (since, as previously pointed out, both of these could be used for compliance in April 2009). Yet, as seen in Figure 3, the convenience yield is much more volatile, although it follows the same trend as other implied convenience yields. This is so, due to the fact that the interest rate effect is minimised closer to maturity and it was pronounced that some differences still persisted between the spot and Dec08 futures.

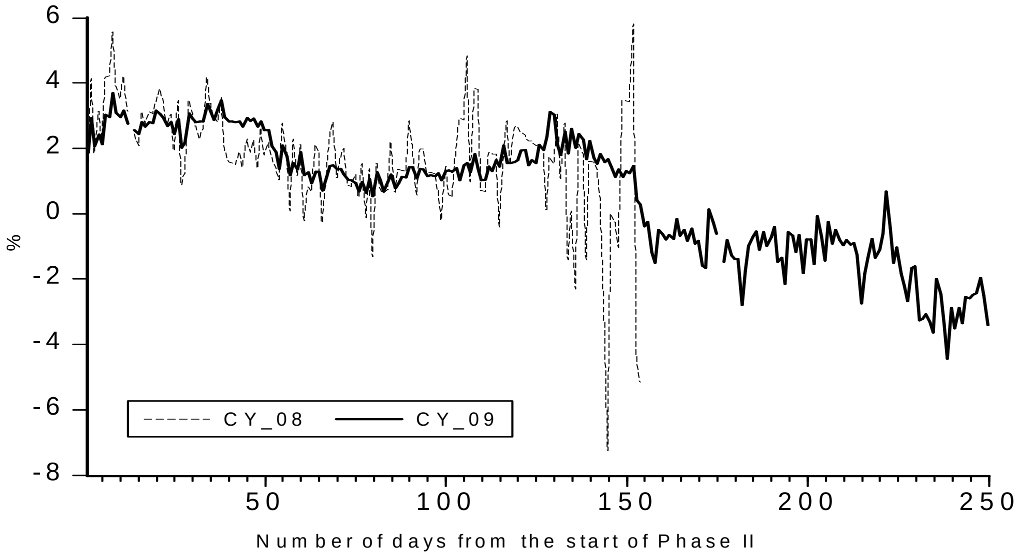


Figure 3

Implied convenience yield from December 2008 futures compared to that from December 2009 futures.

One-sample t-tests on the implied convenience yield from the Dec08 contract confirmed the results in Figure 3 and rejected the 0 mean assumption, contradicting ex ante expectations.

3.3.2 Cointegration Between Spot and Futures

The first step in testing cointegration is to ascertain that the variables have the same level of integration. If they do, it can be tested whether they follow the same processes, i.e. whether the linear combination between them is stationary. For this purpose, the spot and futures prices of both traded permits – EUA and CER – were analysed. In addition, it was tested whether adding interest cost (interest rate times the time-to-maturity) to the cointegrating vector can help explain the long-run relationships, thus, in essence strictly testing the cost-of-carry model with zero convenience yield.

Testing for Unit Root in the Time Series

Three different unit root tests, Augmented Dickey-Fuller (ADF), Philips-Perron (PP) and GLS modified Dickey-Fuller (DF-GLS), were used to test whether the asset prices follow a random walk (have a unit root) or are mean reverting in the long term (stationary). Further, it would be interesting to test whether the data is integrated of order one, i.e. I(1), or has an even higher order of integration.

All unit root tests, reported in Appendix 6, fail to reject non-stationarity in level values for EUA spot and futures prices as well as for the interest rate (12-month Euribor) for the respective time periods. The same applies for CER as demonstrated in Appendix 8. However, the same tests reject it in all cases of first differences. Hence, all the observed time series are difference stationary integrated of order one. In conclusion, the necessary condition for the cointegration analysis is satisfied, which allows us to proceed to further investigate the relationship between the spot and the futures.

Testing for Cointegration

Having determined that all the price series are I(1), it can now be tested, whether they follow the same stochastic trend, i.e. whether the difference between them is mean-reverting in the long run. The EUA Dec11 futures were chosen for this purpose. The reasoning behind this is that due to the absence of listed Phase III futures, Dec12 futures somewhat carry this purpose due to bankability. Furthermore, since the Dec11 futures deviate the most from their theoretical values (after Dec12 futures) proving cointegration in this specific case would suggest that this might hold in the case of shorter-term futures as well.

To prove cointegration, one has to prove that the obtained residuals (u_t) in equation (5) are stationary. Hence, the same procedures are followed as in the case of testing the unit root in the price series. However, the critical values of the tests will be changed due to the fact that regressing level values might lead to spurious regressions (Hill et al. 2007). Further, the Johansen test, a more sophisticated measure, is used to verify these results, while the Engle-Granger test results are provided more for the purpose of intuitive explanations.

Firstly, the case of EUA is considered. When testing cointegration simply between EUA spot and futures values according to equation (5), unit root tests are not able to reject non-stationarity in the residuals, even when interest cost (interest rate – approximated by the 12-month Euribor – times time-to-maturity) is added to the cointegrating equation (see Appendix 9). Hence, with the Engle-Granger methodology one cannot reject the null-hypothesis of non-stationarity of the residuals and must conclude that the EUA spot and the December 2011 futures prices are not cointegrated, although the visual inspection of the price series, shown in Appendix 5, definitely suggests that there is a strong relationship between the spot and the futures.

To further check these results, Johansen cointegration test was carried out, with the results in Appendix 10. Though, in a two variable setting the results should not be significantly different from those attained with the Engle-Granger method (Alexander 2001), which indeed confirm the unit root tests, whereas in the three variable case (when adding interest cost to the relationship, computed as before), the Johansen test reports the existence of one cointegrating relationship. Therefore, adding the interest cost to the system does somewhat help explain the relationship between the spot and futures, due mainly to the recent drastic changes in interest rates due to the financial markets' situation.

An error correction model can finally be fitted. First, the long run, cointegrating relationship is estimated by the Johansen procedure:

$$\ln S_t^{EUA} = 0.1174 + 0.9931 \ln F_t^{EUA} - 0.9512 IntCost - 0.0008t \qquad (6)$$

(-15.36)* (1.9)***

where lnS_t and lnF_t are the spot and futures values of EUA in natural logarithms and *IntCost* denotes interest cost. The t-statistics, given in parentheses, show that the latter two are significant at the 1% and the 10% level, respectively.. The interest cost is calculated as before, i.e. the interest rate for the respective period (approximated by the 12-month Euribor) times time-to-maturity, i.e. r_t(T-t).

The short-term dynamics between the observed variables (reported in Table 2) are obtained by regressing, in a fashion similar to the system of equation (4), the changes in the variables (differenced values) on the lagged changes in all of the variables together with the lagged errors from the equation (6).

EUA	ΔlnS_t		ΔlnF_t		$\Delta IntCost_t$	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
e_{t-1}	-0.1687	-1.80***	-0.1436	-1.59	-0.0091	-3.58*
ΔlnS_{t-1}	-0.0129	-0.04	0.2512	0.90	0.0083	1.07
ΔlnF_{t-1}	0.1074	0.36	-0.1447	-0.50	-0.0079	-0.98
$IntCost_{t-1}$	0.2736	0.12	0.1321	0.06	0.3379	5.61*
trend	0.0000	0.04	0.0000	-0.05	0.0000	-3.78*
cons	-0.0002	-0.05	0.0000	-0.01	0.0002	2.42**

Table 2
Vector Error Correction Model on EUA: Estimating effects from the lagged values. The appropriate lag order was chosen based on the Schwarz Bayesian information criterion (SBIC).
*sig at the 1% level
**sig at the 5% level
***sig at the 10% level

The error term (denoted e_{t-1} in the table) shows no significance in explaining the EUA futures prices and is significant only at the 10% level in explaining the EUA spot price (denoted ΔlnS), thus confirming the statistical testing and implying that the cointegrating relationship between the EUA spot and futures prices is relatively weak. However, the error term does have a highly significant impact on the interest cost (denoted ΔIntCost). Furthermore, there exists no significant lead-lag relationship between the spot and the futures (it is possible that using intraday data would change this result).

The reasons behind the weak relationship can be twofold. Firstly, as brought up before, stochastic convenience yields can affect the link between spot and futures. Figure 3 shows that there is a shift in convenience yield from positive to negative values at the end of 2008, which should be reflected in the residuals from the cointegrating vector. As presented in Appendix 5, Panel B, major discrepancies in the relationship between the log-prices still exist in the first half of the time period, exhibiting no similarities with the trend of the convenience yield (this is illustrated by the bivariate case, though adding interest cost to the relationship does not change the picture significantly). Secondly, when calculating the implied convenience yields, according to the cost-of-carry model, the unit slope is imposed to the relationship between the spot and the future. Hence, it might just be that the coefficient, through which the asset prices are related, has been subject to change over the time period, which in this case seems to be the more reasonable inference.

Next, cointegration in the other exchange-traded permit in the EU ETS – CER – will also be analysed here. A quick glance at the price series presented in Appendix 7 reveals that the CER spot and December 2011 futures follow practically the same path after some convergence at the beginning of Phase II. In addition, based on the unit root tests as well as the stationarity test on residuals reported in Appendix 9, cointegration can be proved to exist between the spot and the futures even without adding any interest cost to the relationship. Furthermore, the Johansen test in Appendix 10 clearly confirms that there does exist a cointegrating relationship both with and without interest cost. However, based on the information criteria undoubtedly the model including the interest cost should be preferred, and as it is of interest to test the cost-of-carry model, the long-term relationship between CER and the following variables was estimated[2]:

$$\ln S_t^{CER} = 0.3312 + 0.8080 \ln F_t^{CER} + 0.9974 IntCost + 0.0004t \qquad (7)$$

(-26.14)* (-3.23)*

where the variables have an identical interpretation as in the EUA case. Consequently, since the tests unanimously prove the existence of cointegration, an error correction model can be estimated. Table 3 reports the results.

CER	$\Delta \ln S_t$		$\Delta \ln F_t$		$\Delta IntCost_t$	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
e_{t-1}	-0,6998	-4,57*	-0,4766	-2,91*	-0,0049	-1,88***
$\Delta \ln S_{t-1}$	0,2703	1,58	0,5202	2,85*	0,0039	1,35
$\Delta \ln F_{t-1}$	-0,0937	-0,57	-0,3482	-1,99**	-0,0030	-1,06
$IntCost_{t-1}$	-3,7529	-1,08	-3,1518	-0,84	0,6942	11,60*
trend	0,0000	-0,27	0,0000	0,37	0,0000	-0,19
cons	0,0024	0,44	-0,0029	-0,49	-0,0002	-1,88***

Table 3
Vector Error Correction Model on CER: Estimating effects from the lagged values. The appropriate lag order was chosen based on the Schwarz Bayesian information criterion (SBIC).
*sig at the 1% level
**sig at the 5% level
***sig at the 10% level

[2] Again using the Johansen procedure.

The error terms (denoted e_{t-1}), or the short run deviations from a long-run equilibrium, have negative coefficient values, -0.6998 for the spot returns (denoted ΔlnSt), -0.4766 for the futures returns (denoted $\Delta \ln F_t$) and -0.0049 for the changes in the interest cost (denoted $\Delta IntCost_t$), significant at the 1%, 1% and 10% level, respectively. This implies that in the case of a shock the spot and futures prices move at a fairly fast rate back towards the mean reverting equilibrium level, while the interest cost has a less important role in the relationship.

Another even more important result in this context is that on the CER market, the spot price Granger-causes or leads the futures prices at the 99% confidence level. This means that the spot log-returns can explain or forecast the futures log-returns (at least the futures maturing in 2011). As indicated before, this is more typical for the energy commodity markets and is a sign of rigid supply and that the market is not efficient (Alexander 2001). However, it should be noted that the market is relatively young (covering slightly more than 160 observations here) and also fairly illiquid. This could also explain the results and, the phenomenon may therefore be subject to change.

However, one aspect that might influence the results is the fact that the CER spot and futures are traded on different exchanges (on BlueNext and NordPool, respectively). Benz and Klar (2008) find some evidence that in the case of EUA, exchanges that are more liquid and have lower transaction costs react faster to new information, although, the less liquid exchange to some extent also contributed to the price discovery.

Since all tests, as well as the Vector Error Correction model, indicate that the CER spot and futures prices are indeed cointegrated - follow the same trend in the long run - it can be tested whether these are related through the cost-of-carry model. From equation (3), it can be seen that in the estimated model it should hold that

$$\ln S_t = 1 \ln F_t - 1 r_t (T - t) \qquad (8)$$

In other words, it should be tested whether the coefficients for the log futures price and the interest cost are equal to 1 and –1, respectively. However, the positive near unity coefficient value for the interest cost in the equation (7) allows rejection of the cost of carry model for CER futures pricing without any formal testing. This is also indicated by the relatively week correlations by the 12-month Euribor and CER futures prices (as compared to EUA), which are presented in Appendix 4.

When looking at equation (6), the EUA futures prices seem to evolve in accordance with the cost-of-carry model. Nevertheless, for this relationship to hold, the condition of cointegration must be satisfied, for which, as previously proved, the results are rather mixed.

Conclusion

The market price of emitting carbon dioxide is fairly volatile and highly dependent on the so-called market fundamentals (such as the demand for energy commodities and extreme changes in weather), because of the vertical supply curve of allowances. Nevertheless, the most important factors from risk management perspective are still the institutional factors or regulatory risk related to the future design of the scheme, the most relevant being how large the total cap set in Phase III will be. Other factors are how the allowances will be auctioned and, more importantly, whether, how and when the EU ETS will be linked to the flexible mechanisms, JI and CDM, and other emission trading schemes. In any case, a shortage of allowance can be expected to be considerable in Phase III and will probably occur also in Phase II. The aforementioned risk factors, however, will have substantial impact on the prices in the mid-term.

In conclusion, forecasting the carbon price is quite a challenging task.

A more relevant question from a compliant’s perspective is how to effectively hedge the carbon risk. For this purpose, the futures market was investigated, based on futures written on EUA and CER, maturing in December 2011. To my knowledge, this is the first study on relationships between the CER spot and futures prices and the first study on EUA in Phase II. While some previous papers have studied the Phase II futures previously (e.g. Uhrig-Homburg and Wagner 2007), their results are dubious, since they used the Phase I spot price for pricing the futures contracts.

At a first glance, the econometric analysis shows that the EUA futures prices seem to develop according to the standard cost-of-carry model. Nevertheless, for this relationship to hold, there must be cointegration between the variables, for which there were not very many strong arguments. The futures in Phase II have turned from normal backwardation to normal contango and convenience yields implied by the EUA futures have evolved rather stochastically while exhibiting ‘term structure’. However, the evidence suggests that it is the change in the direct relationship between the spot and the futures, rather than the stochastic convenience yield that makes the tests fail to prove cointegration.

In contrast, statistical testing revealed that there definitely is a strong cointegrating relationship between the CER spot and futures prices (as well as the interest cost), though the prices are definitely not related through a cost-of-carry relationship.

While the EUA price series in Phase I exhibited extreme volatilities due to the regulatory issues and lack of experience in the market, carbon prices have shown wide swings in Phase II as well, due mainly to changing perceptions about the level of emissions during the recession and liquidity problems among companies caused by the credit crisis. Yet, despite all the uncertainties, it is very unlikely that a structural break (or price collapse) like the one at the end of Phase I will happen in the future due to the guaranteed and unlimited bankability of EUAs (at least until 2020).

Based on the first year of Phase II of the EU ETS, it can be nevertheless concluded that the futures market does, in the end, provide reasonably effective hedging opportunities (though the statistical tests do not all confirm this due to the rough start in Phase II). Hopefully, the recent trend of liquidity traders entering the market will also make options a more useful hedging tool, which is especially important in the light of all the possible scenarios of the market development.

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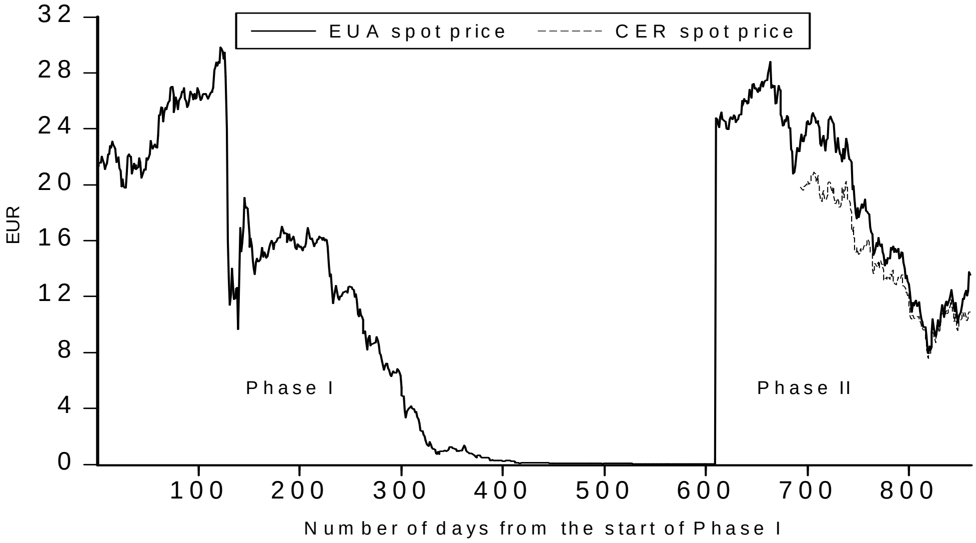
Appendices

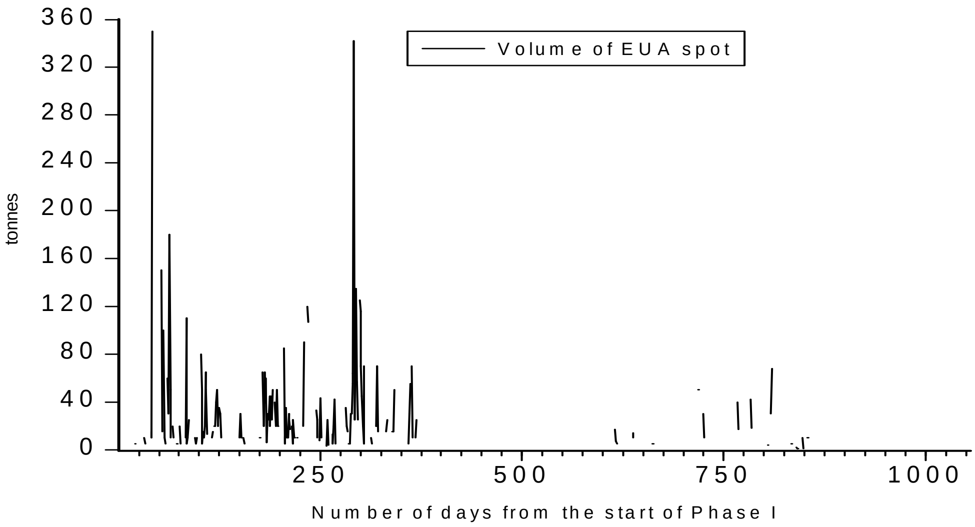
Appendix 1

Daily Spot Prices

Panel A



Panel B



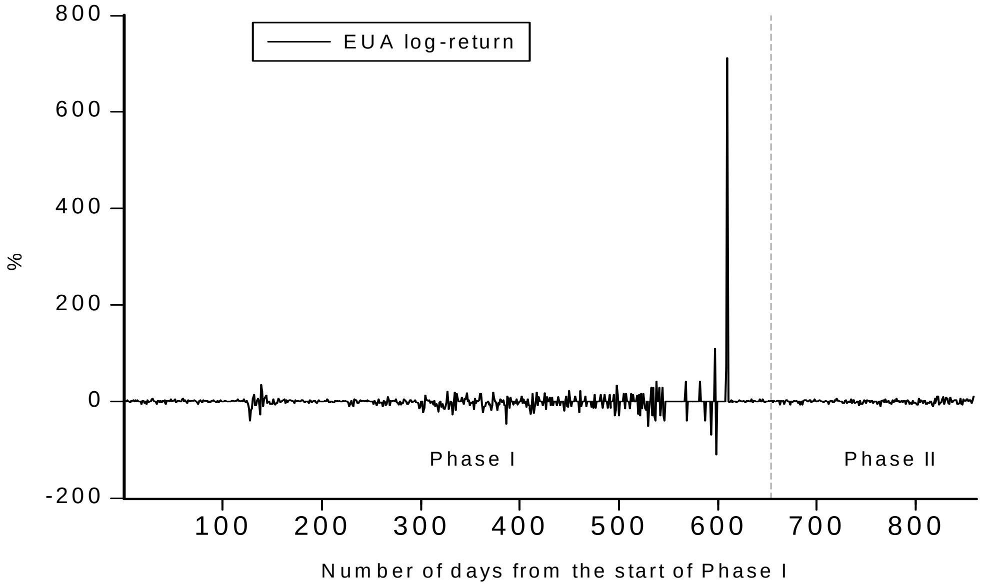
Panel A: Daily closing spot prices of EUA from the beginning of the EU ETS traded on NordPool (24 October 2005-15 April 2009) and CER prices from BlueNext (12 August 2008-15 April 2009).

Panel B: Volume of EUA traded from the beginning of the EU ETS traded on NordPool (24 October 2005-15 April 2009)

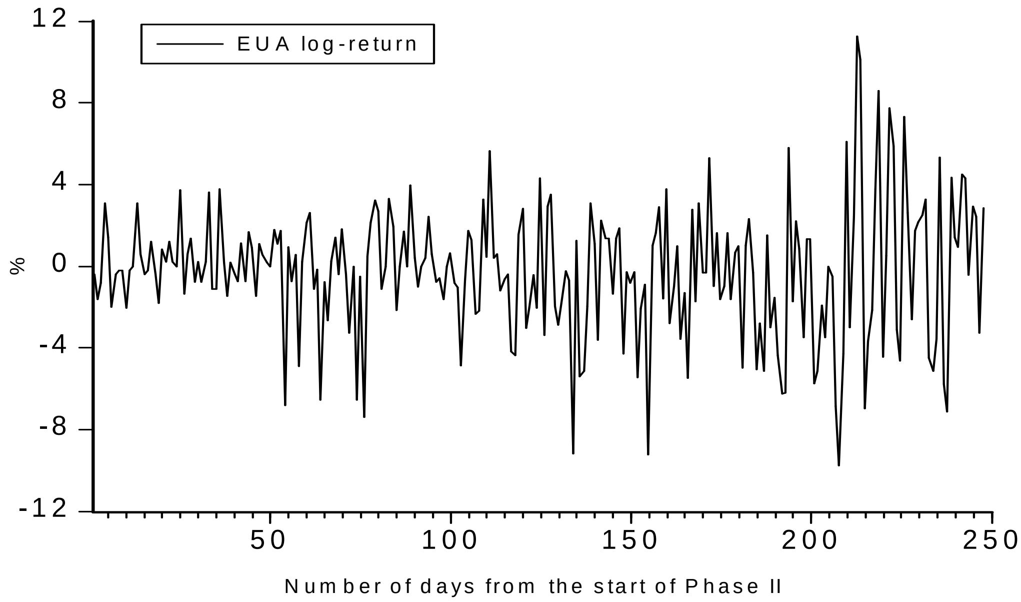
Appendix 2

EUA Daily Log-returns

Panel A



Panel B



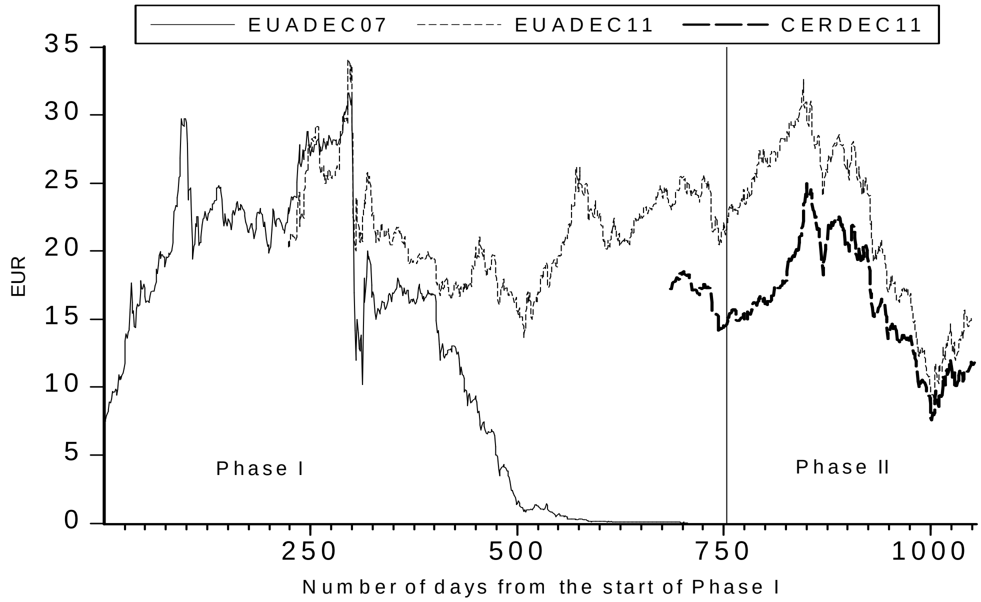
Panel A: Nordpool daily log-returns of EUA in Phase I and II (24 October 2005-15 April 2009)

Panel B: Nordpool daily log-returns of EUA zoomed in on Phase II (15 April 2008-15 April 2009)

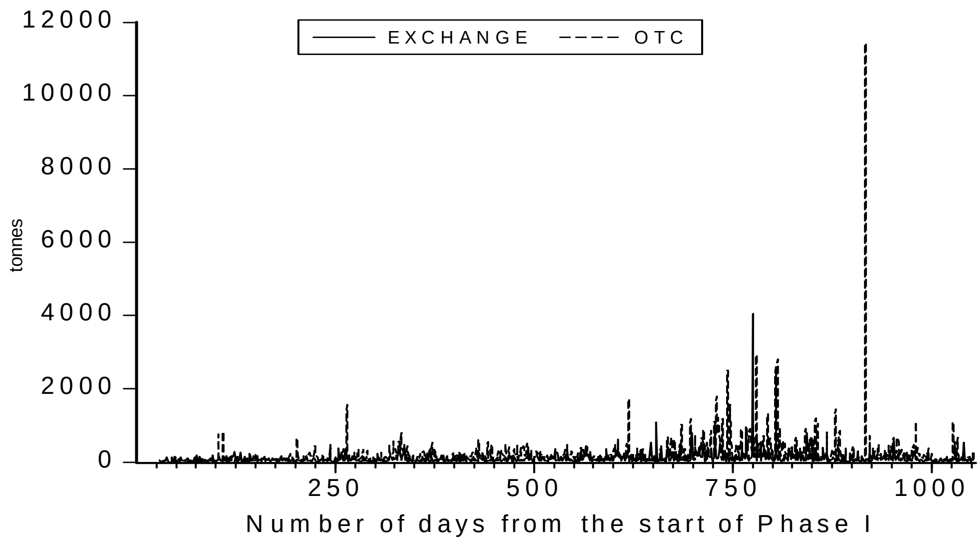
Appendix 3

Daily Futures Prices and Volume

Panel A



Panel B



Panel A: The three futures prices are chosen from NordPool for illustrative purposes:
EUADEC07 - futures on EUA maturing in Dec 2007 (in Phase I),
EUADEC11 - futures on EUA maturing in Dec 2011 (in Phase II), and
CERDEC11 - futures on CER also maturing in Dec 2011.
The vertical line in the graph refers to the start of Phase II.

Panel B: Shows volumes traded in the financial market of the CO_2 allowances (futures written on EUA and CER) on NordPool that were traded in the respective time points ranging from deliveries in 2005 up until 2012.

Appendix 4

Correlations

Matrix I

	EUA	CER	Oil	Coal	Natura~s	Electr~y
EUA	1.0000					
CER	0.9947	1.0000				
Oil	0.9000	0.8933	1.0000			
Coal	0.9216	0.9184	0.8974	1.0000		
Natural_Gas	0.8218	0.8314	0.7004	0.8363	1.0000	
Electricity	0.9127	0.9096	0.8364	0.9019	0.8318	1.0000

Matrix II

	EUA_spot	EUADE~08	EUADE~09	EUADE~10	EUADE~11	EUADE~12	EURIBOR
EUA_spot	1.0000						
EUADEC_08	0.9560	1.0000					
EUADEC_09	0.9995	0.9558	1.0000				
EUADEC_10	0.9987	0.9545	0.9997	1.0000			
EUADEC_11	0.9975	0.9539	0.9991	0.9997	1.0000		
EUADEC_12	0.9962	0.9534	0.9981	0.9991	0.9997	1.0000	
EURIBOR	0.9362	0.9500	0.9388	0.9374	0.9376	0.9371	1.0000

Matrix III

	CER_PNX	CERDE~08	CERDE~09	CERDE~10	CERDE~11	CERDE~12	EURIBOR
CER_PNX	1.0000						
CERDEC_08	0.9976	1.0000					
CERDEC_09	0.9915	0.9955	1.0000				
CERDEC_10	0.9887	0.9928	0.9992	1.0000			
CERDEC_11	0.9856	0.9900	0.9977	0.9994	1.0000		
CERDEC_12	0.9812	0.9863	0.9957	0.9981	0.9990	1.0000	
EURIBOR	0.8749	0.8733	0.8583	0.8547	0.8468	0.8513	1.0000

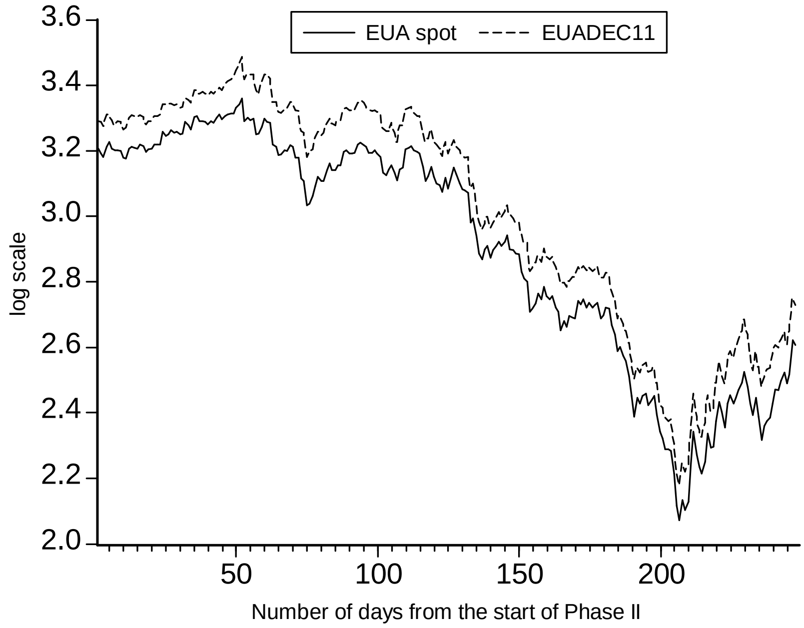
Matrix I and III contain correlations over the time period from 12 August 2008-15 April 2009 (trading period of CER on BlueNext).
Matrix II is calculated over the period from 15 April 2008-15 April 2009 (trading period of EUA in Phase II on NordPool).

Oil is the Brent Crude oil spot price on FOB terms. Coal is from South-Africa on FOB terms. Electricity is the daily average electricity system price on NordPool. Natural gas is from the Henry Hub. All the EUA spot and futures, as well as the CER futures prices are the daily closing prices from NordPool. The CER spot price is the closing price from BlueNext. Euribor represents the 12-month rate.

Appendix 5

EUA Price Series

Panel A



Panel B

Panel A: NordPool EUA spot and Dec 2011 futures values in natural logarithms

Panel B: 'Actual' shows the EUA spot price, and 'fitted' is the value of the EUA spot predicted by OLS regression on 2011 futures (with a constant added). 'Residuals' represents the difference between the actual and fitted values.

Appendix 6

Unit Root Tests on EUA

	Unit root tests					
	ADF	specification	**PP**	specification	**DF-GLS**	lag (min MAIC)
Level values (in natural logs)	p-value		p-value		t-statistic	by DF-GLS
EUA_spot	0.2149	drift, lag 1	0.6709	trend, default lags	-1.415	1
EUADEC_08	0.6357	drift, lag 0	0.8299	trend, default lags	-0.961	1
EUADEC_09	0.1903	drift, lag 4	0.6988	trend, default lags	-1.534	4
EUADEC_10	0.1847	drift, lag 4	0.6699	trend, 10 lags	-1.512	4
EUADEC_11	0.1660	drift, lag 10	0.7247	trend, default lags	-1.385	11
EUADEC_12	0.1815	drift, lag 4	0.7188	trend, default lags	-1.534	4
EURIBOR - 12M	0.5834	drift, lag 5	0.1090	trend, lag 1	-0.094	5
First differences						
EUA_spot	0.0000	drift, lag 0	0.0000	drift, lag 0	(-11.26)*	9
EUADEC_08	0.0000	drift, lag 0	0.0000	drift, lag 0	(-7.165)*	13
EUADEC_09	0.0000	drift, lag 0	0.0000	drift, lag 0	(-10.715)*	15
EUADEC_10	0.0000	drift, lag 0	0.0000	drift, lag 0	(-10.780)*	15
EUADEC_11	0.0000	drift, lag 0	0.0000	drift, lag 0	(-10.669)*	15
EUADEC_12	0.0000	drift, lag 0	0.0000	drift, lag 0	(-10.453)*	15
EURIBOR - 12M	0.0000	drift, lag 0	0.0000	drift, lag 0	(-6.185)*	11

*sig at the 1% level
**sig at the 5% level
***sig at the 10% level

The test results for the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) are given by the Mackinnon approximate p-values, while for the Generalized Least Squares modified Dickey-Fuller (DF-GLS) test only test-statistics are provided.

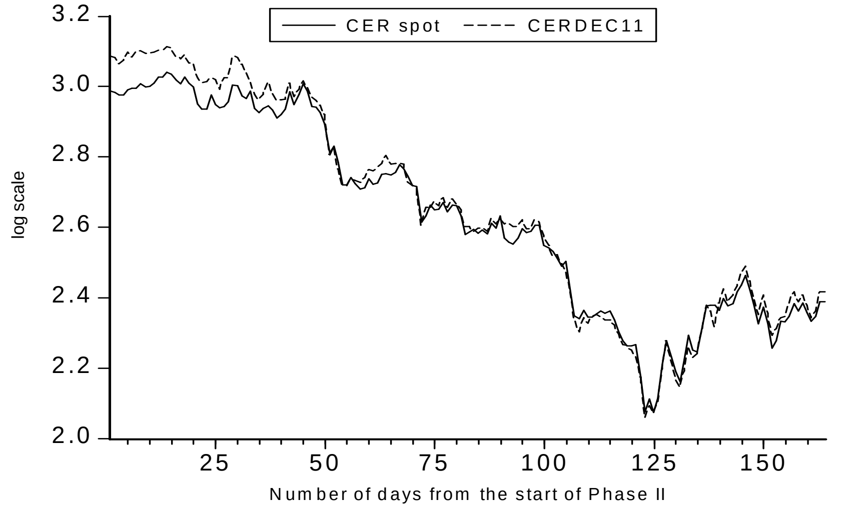
All the EUA spot and futures values (not the 12-month Euribor) have been converted into natural logarithms. The first difference refers also to differences in consecutive natural logarithmic values. The specification column contains information about the process used to obtain the presented (lowest) p-values.

Tests on level values test the null hypothesis of I(1) versus I(0), while the tests on first differences test the null hypothesis of I(2) versus I(1).

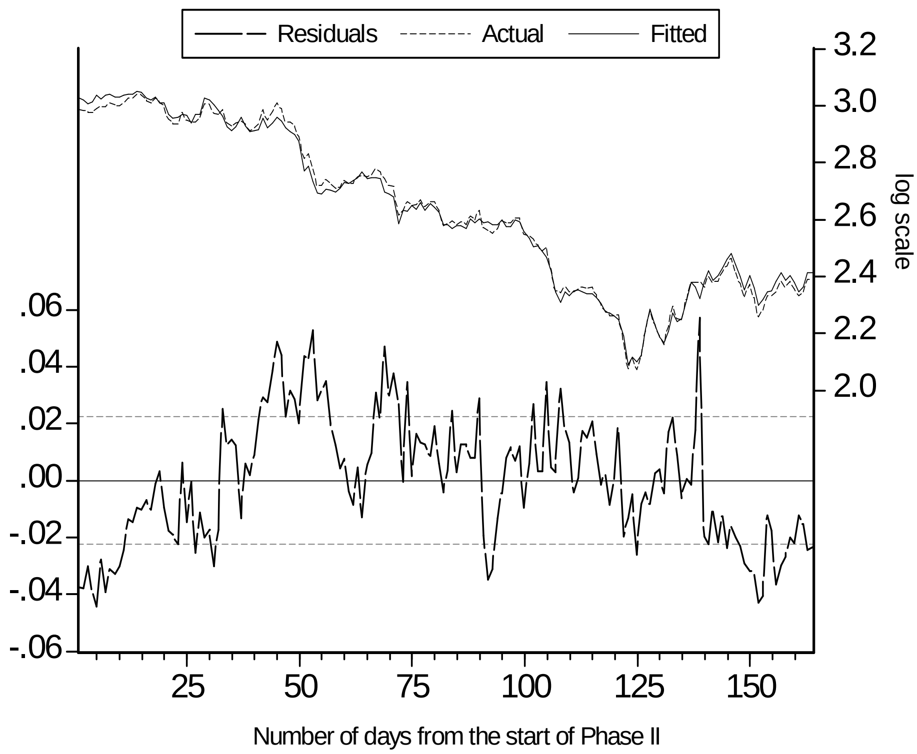
Appendix 7

CER Price Series

Panel A



Panel B



Panel A: NordPool CER spot and Dec 2011 futures values in natural logarithms

Panel B: 'Actual' shows the CER spot price, and 'fitted' is the value of the CER spot predicted by OLS regression on 2011 futures (with a constant added). 'Residuals' represents the difference between the actual and fitted values.

Appendix 8

Unit Root Tests on CER

	Unit root tests					
	ADF	specification	**PP**	specification	**DF-GLS**	lag (min MAIC)
Level values (in natural logs)	p-value		p-value		t-statistic	by DF_GLS
CER_PNX	0.1566	drift, lag 2	0.6997	trend, lag 2	-2.054	2
CERDEC_08	0.5014	drift, lag 1	0.5027	trend, lag 2	-1.561	1
CERDEC_09	0.6809	drift, lag 1	0.6776	drift, default	-1.864	2
CERDEC_10	0.1082	drift, lag 1	0.6635	no trend lag 1	-1.803	1
CERDEC_11	0.0820	drift, lag 12	0.6636	no trend lag 1	-1.603	2
CERDEC_12	0.6560	drift, lag 1	0.6545	drift, default	-1.692	1
EURIBOR - 12M	0.2078	drift, lag 5	0.7601	trend, lag 2	-1.199	2
First differences						
CER_PNX	0.0000	trend, lag 3	0.0000	no trend, lag 3	(-5.369)*	3
CERDEC_08	0.0000	drift, lag 1	0.0000	trend, lag 1	(-5.827)*	3
CERDEC_09	0.0000	drift, lag 1	0.0000	drift, default	(-9.171)*	3
CERDEC_10	0.0000	drift, lag 1	0.0000	trend, lag 1	(-8.880)*	3
CERDEC_11	0.0000	trend, lag 1	0.0000	trend, lag 1	(-5.391)*	3
CERDEC_12	0.0000	drift, lag 1	0.0000	drift, default	(-8.819)*	3
EURIBOR - 12M	0.0007	drift, lag 1	0.0020	trend, lag 5	(-2.938)***	5

*sig at the 1% level
**sig at the 5% level
***sig at the 10% level

The test results for the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) are given by the Mackinnon approximate p-values, while for the Generalized Least Squares modified Dickey-Fuller (DF-GLS) test only test-statistics are provided.

All the CER spot and futures values (not the 12-month Euribor) have been converted into natural logarithms. The first difference refers also to differences in consecutive natural logarithmic values. The specification column contains information about the process used to obtain the presented (lowest) p-values.

Tests on level values test the null hypothesis of I(1) versus I(0), while the tests on first differences test the null hypothesis of I(2) versus I(1).

Appendix 9

Unit Root Tests on Residuals

Panel A: EUA

EUA	Test statistics	Critical values		
Spot and futures		**10%**	**5%**	**1%**
ADF	-2,290	-3,0657	-3,3654	-3,9618
PP	-2,536	-3,0657	-3,3654	-3,9618
KPSS	0,246	0,231	0,314	0,533
Spot, futures and interest cost		**10%**	**5%**	**1%**
ADF	-2,578	-3,4494	-3,7675	-4,3078
PP	-2,839	-3,4494	-3,7675	-4,3078
KPSS	0,248	0,163	0,221	0,38

Panel B: CER

CER	Test statistics	Critical values		
Spot and futures		**10%**	**5%**	**1%**
ADF	-3.651	-3.0657	-3.3654	-3.9618
PP	-4.618	-3.0657	-3.3654	-3.9618
KPSS	0.316	0.231	0.314	0.533
Spot, futures and interest cost		**10%**	**5%**	**1%**
ADF	-4.490	-3,4494	-3,7675	-4,3078
PP	-5.383	-3,4494	-3,7675	-4,3078
KPSS	0.229	0,163	0,221	0,38

Where:
ADF - Augmented Dickey-Fuller test
PP - Phillips-Perron test
KPSS - Kwiatkowski-Phillips-Schmidt-Shin test

The critical values for the unit root tests in case of regressing variables of I(1), i.e. regressing level values of variables with a unit root, were obtained from Phillips and Ouliaris (1990) for the demeaned case. The KPSS test is a complement to the unit root tests, where the posed null hypothesis is that the data is stationarity (as opposed to the unit root tests where the non-stationarity is tested). The KPSS critical values for residual testing are from Shin (1994).

Appendix 10

The Johansen Test

Commodity	Model	Null Hypothesis	Trace Statistic	5% Critical value
EUA	Spot, futures	r=0	12.8226*	18.17
		r=1	3.9496	3.74
	Spot, futures, interest cost	r=0	33.7868	29.68
		r=1	10.4018*	15.41
CER	Spot, futures	r=0	21.0638	18.17
		r=1	2.6287*	3.74
	Spot, futures, interest cost	r=0	40.6294	34.55
		r=1	8.4425*	18.17

The trace statistics show the results of testing the hypotheses of ranks, i.e. the maximum number of cointegrating relationships between the variables. The asterisks indicate the ranks assigned by the test, meaning that the respective null hypothesis cannot be rejected. The lag orders for the test were chosen based on different information criteria and on significance of the lagged values in the VECM. In addition, a trend was added in every case.