Kiel

Working Papers

Kiel Institute
for the World Economy

Carbon Price Dynamics – Evidence from Phase II of the European Emission Trading Scheme

by Wilfried Rickels, Dennis Görlich, Gerrit Oberst, Sonja Peterson

No. 1804| November 2012

Web: www.ifw-kiel.de

Kiel Institute for the World Economy, Hindenburgufer 66, 24105 Kiel, Germany

Kiel Working Paper No. 1804 | November 2012

Explaining European Emission Allowance Price Dynamics: Evidence from Phase II

Wilfried Rickels, Dennis Görlich, Gerrit Oberst, Sonja Peterson

In this paper we empirically investigate potential determinants of allowance (EUA) price dynamics in the European Union Emission Trading Scheme (EU ETS) during Phase II. In contrast to previous papers, we analyze a significantly longer time series, place particular emphasis on the importance of price variable selection, and include an extensive data of renewable energy feed-in in Europe. We show (i) that results are extremely sensitive to choosing different price series of potential determinants, such as coal and gas prices, (ii) that EUA price dynamics are only marginally influenced by renewable energy provision in Europe, and iii) that EUA prices currently do not reflect marginal abatement costs across Europe. We conclude that the expectation of a more mature allowance market in Phase II cannot be confirmed.

Keywords: Carbon emission trading, EU ETS, Carbon price influence factors, Fuel switching

JEL classification: C22, G14, Q54

Wilfried Rickels
Kiel Institute for the World Economy
24105 Kiel, Germany
E-mail: wilfried.rickels@ifw-kiel.de

Dennis Görlich
Kiel Institute for the World Economy
24105 Kiel, Germany
E-mail: dennis.goerlich@ifw-kiel.de

Gerrit Oberst
Friedrich-Alexander Universität Nürnberg-Erlangen 90403 Nürnberg, Germany
E-mail: goebs@gmx.net

Sonja Peterson
Kiel Institute for the World Economy
24105 Kiel, Germany
E-mail: sonja.peterson@ifw-kiel.de

The responsibility for the contents of the working papers rests with the author, not the Institute. Since working papers are of a preliminary nature, it may be useful to contact the author of a particular working paper about results or caveats before referring to, or quoting, a paper. Any comments on working papers should be sent directly to the author.

Coverphoto: uni_com on photocase.com

Carbon Price Dynamics – Evidence from Phase II of the European Emission Trading Scheme

Abstract:

In this paper we empirically investigate potential determinants of allowance (EUA) price dynamics in the European Union Emission Trading Scheme (EU ETS) during Phase II. In contrast to previous papers, we analyze a significantly longer time series, place particular emphasis on the importance of price variable selection, and include an extensive data of renewable energy feed-in in Europe. We show (i) that results are extremely sensitive to choosing different price series of potential determinants, such as coal and gas prices, (ii) that EUA price dynamics are only marginally influenced by renewable energy provision in Europe, and iii) that EUA prices currently do not reflect marginal abatement costs across Europe. We conclude that the expectation of a more mature allowance market in Phase II cannot be confirmed.

1. Introduction

In 2005, the European Union (EU) established its emission trading scheme (EU ETS) as a major pillar for reaching their country specific Kyoto targets (either stemming directly from the Kyoto agreement or the so-called EU Burden Sharing Agreement) in an efficient, cost minimizing way. The EU ETS is a cap-and-trade scheme for CO_2 emission allowances (EUA) that covers the CO_2 emissions of around 11,000 installations in the major energy intensive sectors of now 30 participating countries (EU member states, Iceland, Liechtenstein, Norway). In 2009, ETS installations were responsible for 43 percent of total EU greenhouse gas emissions (EEA 2011). Total emissions from the EU ETS installations amounted to an average of 1.982 $MtCO_2$-equivalent per year between 2008 and 2010. The major share of these emissions (72.5 percent) stemmed from combustion installations. The cement, clinker and lime production added another 8 percent, mineral oil refineries 7 percent, the production of pig iron and steel 6 percent. Emission from other sectors varied between 0.5 and 1.5 percent (EEA 2011, p. 42). From 2013 onwards, the EU ETS will also cover the aluminum sector and the petrochemical industry as well as nitrogen emission of some sectors. The EU ETS is currently the largest ETS worldwide with a market value that has been rising continuously from USD 7.9 billion (EUR 6.35 billion) in 2005 to USD 119.8 billion (EUR 90.32 billion) in 2010 (Linacre et al. 2011).

The first phase of the EU-ETS (2005-2007) can be regarded as a start-up and test period. Currently, the scheme is at the end of Phase II (2008–2012). In both phases basically all allowances where grandfathered and the allocation was specified by member states in National Allocation Plans (NAPs) which had to be approved by the EU Commission. The NAPs also specify the maximum share of credits from the project based mechanisms under the Kyoto Protocol, namely the Clean Development Mechanism (CDM) and Joint Implementation (JI) and (see UNFCCC 1997, 2003 for details) that can be used for compliance in the EU ETS. From Phase III on, allowances will be centrally allocated by the EU Commission following harmonized rules. In line with the target to reduce the emissions of the ETS sectors by 21 percent relative to 2005 by 2020 the overall allocation will be reduced by 1.74 percent annually from 2013 on. Furthermore, a larger share of allowances will be auctioned (see EU 2009 for details). Throughout Phase I, banking and borrowing was allowed between years, but not between Phase I and Phase II.[1] From Phase II onwards, unlimited banking is allowed. For a more detailed description of the development and details of the EU ETS see for example Kruger and Pizer (2004), Convery and Redmond (2007), Convery (2009), EEA (2011), and Heindl and Löschel (2012).

EUA prices were quite volatile during Phase I, first rising alongside natural gas prices while reacting nervously to news concerning the final allowance allocation. When first reliable data on the actual emissions of the covered installations became available in May 2006 it became clear that emissions fell short of allocated emissions. Prices then decreased sharply and practically hit zero by mid-2007. So far, Phase II showed less volatility and jumps but still a significant downward trend in prices to the end of the phase. EUA future trading for Phase III (2013-2020) is already frequently taking place indicating that emission trading will remain an important instrument for emission control in the European Union, irrespective of the future design of international climate mitigation.

---

[1] The only exception was France, where a small portion of allowances could be transferred from Phase I to Phase II.

Not surprisingly, several studies have been concerned with the potential and actual cost savings of the EU ETS and with the efficiency and specifics of the market. A rather comprehensive literature review follows in Section 2. In particular, the price dynamics of EUAs in Phase I have been studied extensively against the background that, in theory, the allowance price should reflect marginal abatement costs (e.g., Mansanet-Bataller et al. 2007; Rickels et al. 2007; Alberola et al. 2008; Hintermann 2010). Authors found little evidence for theoretically important determinants such as fuel switching. However, these studies have analyzed a new and immature market which was significantly influenced by uncertainty about transaction costs and announcements regarding the regulatory framework (Alberola et al. 2008; Alberola and Chevallier 2009; Montagnoli and de Vries 2010; Chevallier 2011; Conrad et al. 2012). In Phase II the market was expected to gain more maturity so that price dynamics can be explained to a larger extent by fundamental factors. Indeed, Bredin and Muckley (2011), and Creti et al. (2012) provide first evidence that a stable long-term relationship between market fundamentals like coal, gas, oil prices and the EUA price is establishing.

The main goal of our study is to shed more light on the maturity and price determinants of the EU-ETS in Phase II by not only analyzing a longer time series that covers data from almost the entire Phase II, but also by including extended data especially on the fluctuations of renewable power provision in Europe. In the end, we cannot confirm the expectation of a more mature market and show i) that discrepancies between existing studies are to certain extend explain by choosing different price series to reflect the influence of e.g. the coal and gas price, ii) that EUA price dynamics are only marginally influenced by fluctuations in renewables power provision in Europe, and iii) that therefore EUA prices currently do not reflect marginal abatement costs across Europe.

The paper proceeds as follows. In the next section we will give some background on the EU ETS and the determinants of EUA prices. In this context we also develop a small theoretical model that explains the expected impact of different market fundamentals. Furthermore, we give a comprehensive overview of the relevant literature and explain the contribution of this paper. Section 3 describes how we select our data where we use auxiliary regressions for the identification of possible price series. Section 4 presents our empirical analysis and its results. Section 5 discusses the results and concludes.

2. Price Determinants in the European Emission Trading Scheme (EU-ETS)

2.1 Theoretical Considerations

The theoretical discussion about emission trading has started long before the launch of the EU ETS. In particular, the seminal contributions by Montgomery (1972) or Tietenberg (1985) provide a rigorous analysis of the various properties of such a market-based approach. They show that emission trading allows equating marginal abatement costs to the allowance price across the various emission sources given that transactions costs are sufficiently low and market liquidity is sufficiently high. Theoretically, it allows achieving a certain target at minimal costs, provided that the penalty for non-compliance is sufficiently high (see e.g., Schmalensee 2012). It remains to be tested empirically whether the EUA market indeed meets the requirements for efficiency and whether the EUA price is, as predicted by theory, driven by marginal abatement options that are used to equate demand and supply. Driving factors of supply, abatement costs and demand are discussed in a number of studies (Sijm et al. 2005, Christiansen et al. 2005, Kanen 2006).

Due to the limited possibilities of banking and borrowing and the rather small amount of emission reductions via CDM and JI supply of allowances is basically fixed and determined by policy decisions on the total amount of allocated allowances. According to standard economic theory under certainty and no transaction costs, a positive price for emission allowances requires that the overall supply of allowances is less than emissions under a fictional business-as-usual (BAU) scenario. Unexpected deviations from the BAU due to, e.g., higher economic growth increase the gap between potential and allowed total emissions and lead to higher allowance prices. For example, the economic downturn after the financial crisis was accompanied by an estimated decrease in energy-related CO_2 emissions of 3% (IEA 2009).

Since—abstracting from very long term investments like carbon capture and storage—CO_2 emissions cannot be reduced by end-of-the-pipe technologies, the long-term marginal abatement cost are determined by investment decisions in low-carbon energy utilities and energy efficiency. Because of long investment cycles in the energy sector (dominating the EU-ETS) the incumbent technology could still prevail for several decades (Arthur 1989; Acemoglu et al. 2012; Kalkuhl et al. 2012). Heindl and Löschel (2012) report based on survey data from EU ETS installations in Germany that only 5.4 percent of the current emissions arise from installations with an average remaining life-cycle up to 10 years, whereas the majority of emissions (81.9 percent) arise from installations with an average remaining life-cycle from 15 to 20 years.

Consequently, abatement options under the EU ETS are mainly short-term decisions, such as reducing overall output or using fuels with lower carbon content. Output restrictions are a limited option, in particular for the electricity sector, where supply has to match demand in order to ensure grid stability. In the short run, the demand for electricity is rather inelastic or even inelastic (e.g., Rickels et al. 2007; Hintermann 2012). Therefore, the choice of the dispatch order plays a crucial role for short-run carbon abatement. The dispatch order determines the sequence of different power plants brought into operation (Kanen 2006). It is applied particularly in the provision of medium and peak load energy, which is mainly provided by coal and natural gas (Schiffer 2005). Changing the dispatch order, e.g. switching from coal to natural gas, allows a power producer to reduce its CO_2 emissions per MWh by between 40 and 60 percent. In fact, this so-called fuel switching has been argued to be the single most important short run abatement measure for installations in the power and heat sector (e.g., Christiansen et al. 2005; Kanen 2006; Bunn and Fezzi 2008). The cost of fuel switching is determined by the (relative) prices of fossil fuels, and in an efficient market, the EUA price should react to changes in these prices as well. Delarue et al. (2010) confirm the (theoretical) importance of fuel switching for EUA prices.

Furthermore, weather variations are important as they should influence electricity demand as well as the generation of renewable energy, which both have an impact on the demand for allowances and thus allowance prices. (a) Extreme temperatures, i.e. more heating or cooling degree days can affect electricity demand of households (e.g. Considine 2000).[2] (b) Precipitation determines reservoir levels for hydropower generation which is a common traditional renewable energy source that constitutes a significant share in power production especially in Nordic countries (ranging from about 50 in Sweden to almost 100 percent Norway). Hydropower has lower marginal costs than conventional generation (Hintermann 2010) and is mainly used for base load provision (Schiffer 2005). Consequently, lower reservoir levels in particular are expected to have a (positive) influence on EUA prices because they imply that base load provision from

---

[2] Note that the relation between temperature and energy demand is nonlinear (u-shaped) (Boudoukh et al. 2007; Bunn and Fezzi 2008). Temperatures below a certain threshold potentially increase electricity and heat demand for heating purposes. Similarly, temperatures above a certain threshold potentially increase electricity demand for cooling purposes. Both events can thus result in more emissions, higher EUA demand and, hence, a higher EUA price.

hydropower has to be replaced by conventional generation. In Denmark, for example, carbon emissions from the power and heat sector almost doubled in 1996 compared to 1990 because 1996 was an exceptionally dry year. This also implied an increase in coal-fired power generation exported to Norway and Sweden (Christiansen et al. 2005). (c) Wind speed influences the supply of wind power and (d) solar radiation that of solar power. The capacity of wind- and solar power increased rapidly over the past decade, e.g. wind power capacity accounted for 16 percent in 2010 (down from even 39 percent in 2009), and solar photovoltaics for 23 percent of newly installed European power generating capacity (Wilkes and Moccia 2010; Jäger-Waldau 2012). In particular, their power provision for peak load and, therefore, spot electricity provision has rapidly increased. In fact, spot electricity prices even became negative for some hours during the last two years due to very favorable weather conditions (Beneking 2010).

To illustrate all these aspects we set up a simple, stylized model where *n* power producers can choose between gas-based electricity *g* and coal-based produced electricity *c*. A representative power producer *i* then faces the following simple optimization problem, where we assumed linear-quadratic costs functions for the electricity generation process:

$$\mathrm{p}(c_i + g_i) - p_c \alpha c_i^2 - p_g \beta g_i^2 - \pi(e c_i + g_i). \qquad (1)$$

The parameters p, p_c, p_g, and π are the prices for electricity, coal, gas, and emission allowances, respectively. The parameters α and β indicate the necessary amount of the corresponding fuel to produce the electricity and the parameter *e* measures the carbon content of coal relative to gas which is normalized to be one.[3] With the quadratic-linear costs functions we assume that power producers need to use less efficient power plants in their dispatch order for increasing the electricity produced by fuel. In reality the costs are more likely to be described by a piecewise linear function with jumps between the various power plants. Additionally, we assume that overall power production has to satisfy overall electricity demand *X* and that there is an emission cap of *NAP*:[4]

$$X = \sum_{i=1}^{n} c_i + \sum_{i=1}^{n} g_i \qquad \text{and} \qquad NAP \geq e\sum_{i=1}^{n} c_i + \sum_{i=1}^{n} g_i. \qquad (2)$$

We impose $eX > NAP > X$, implying that the emission cap is binding with respect to complete coal-based electricity production but not to complete gas-based electricity production. Solving this simple optimization problem for *n* firms which are assumed to be price takers results in the equilibrium permit price:

$$\pi = \frac{\mathrm{X}(p_c\alpha + p_g\beta e) - NAP(p_c\alpha + p_g\beta)}{\frac{n}{2}(e-1)^2}. \qquad (3)$$

Partial derivatives of (3) allow us to determine the influence of electricity demand, total amount of allowances, and fuel price on the permit price:

---

[3] That means $e = \frac{e_c\alpha}{e_g\beta}$ where e_c is the emission factor of coal and e_g the emission factor of gas with $e > 1$. For a more detail analysis with respect to fuel specific heat rates and emission factors see for example Taschini and Urech (2010).

[4] Consequently, we abstract from the possibility to pay the penalty in case it is lower than the permit price because that would in our simply model imply only an adjustment of *n*. Moreover, we abstract from allocating certain amounts of allowances to power plant producers. This would allow determining whether a power producer is a net seller or buyer of allowances which would be in particular of interest in case of producer specific parameters α and β.

$$\frac{\partial \pi}{\partial X} = \frac{p_c + \beta p_g e}{\frac{n}{2}(e-1)^2} > 0, \qquad \frac{\partial \pi}{\partial NAP} = -\frac{\alpha p_c + \beta p_g}{\frac{n}{2}(e-1)^2} < 0 \qquad (4)$$

$$\frac{\partial \pi}{\partial p_c} = \frac{\alpha(X-NAP)}{\frac{n}{2}(e-1)^2} < 0 \qquad \frac{\partial \pi}{\partial p_g} = \frac{\beta(eX-NAP)}{\frac{n}{2}(e-1)^2} > 0 \quad (5)$$

The signs of the price changes in (5) can be derived from (2).[5] The permit prices thus decreases if the total amount of allowances increases and increases if overall electricity consumption increases. As discussed, the total amount of allowances is determined by political decision. The electricity consumption is expected to be influenced in the short-run by economic activity and weather variations whereas efficiency improvements are expected to take place only in the long-run. A higher provision of carbon-free energy due to higher wind speeds or higher solar radiation is expected to decrease the amount X which needs to be provided by conventional power producers and would therefore reduce the EUA price.

The derivations (5) also show that if the fuel price of coal increases, the permit price decreases because the power plants substitute more CO_2-intensive coal-based electricity consumption with less CO_2-intensive gas-based electricity consumption and vice versa for an increase of fuel price for gas. The simple optimization problem provides a straightforward derivation of the fuel switching price *fs*:

$$fs = \frac{2(p_g \beta g_i - p_c \alpha c_i)}{e-1} \text{ (6).}$$

The fuel switching price indicates the allowance price at which a power producer is indifferent between using either coal or gas for producing electricity. Consequently, it is increasing in the gas price and decreasing in the coal price. For example, if the gas price increases (and hence the fuel switching price), power producers would switch to coal. The resulting additional emissions would lead to a higher demand for EUAs and therefore a higher allowance price.[6]

2.2 Empirical Evidence

Based on the theoretical considerations, a growing number of ex-post studies that fall into different categories and use different approaches, try to explain the EUA price movements and to analyze the relevance of the identified factors as well as the efficiency of the market. An earlier summary of findings that is extended here is given by Ellerman et al. (2010).

A first strand of literature investigates the impact of coal, gas, and oil prices, economic activity and weather variations on the EUA prices on a daily basis mostly for Phase I only. They find a positive influence of both

---

[5]

$$X = \sum_{i=1}^{n} c_i + \sum_{i=1}^{n} g_i < e\sum_{i=1}^{n} c_i + \sum_{i=1}^{n} g_i = NAP < e\left(\sum_{i=1}^{n} c_i + \sum_{i=1}^{n} g_i\right) = eX$$

[6] In the absence of emission allowances, the dispatch order between coal and natural gas can be determined by comparing the dark and spark spread. The dark (spark) spread is the gross margin between the revenue from selling one MWh of electricity from a coal (gas)-fired power plant having bought the amount of coal (gas) necessary to produce one MWh of electricity. Thus, the spreads allow for a comparison between the relative profitability of coal- and gas-fired power plants.

the gas and the oil price on the EUA price (e.g. Mansanet-Bataller et al. 2007; Rickels et al. 2007; Alberola et al. 2008; Hintermann 2010).[7] However, concerning for example the oil price, it remains unclear if this can be attributed to a fuel switching effect, to the correlation between the oil and gas price, or rather to the correlation between the oil price and economic activity. The studies disagree on the influence of the coal price. While Mansanet-Bataller et al. (2007) and Hintermann (2010) find no influence of the coal price, it is negative, as theory would predict in Rickels et al. (2007) and Alberola et al. (2008). It is important to note that almost no study uses the same set of price series in explaining the influence of fuel prices on EUA prices. For example, Mansanet-Bataller et al. (2007) use the European Carbon Index to reflect the price level of over-the-counter (OTC) forward EUA trading; Alberola et al. (2008) use the EUA spot price negotiated at the Powernext Carbon; Rickels et al. (2007) and Hintermann (2010) use the OTC price series for spot trading provided by Point Carbon. A similar situation can be observed for the coal and gas price series used.[8] Therefore, different results potentially stem from differing explanatory variables and there is only limited information about the actual fuel prices relevant for a power utility in its decision about fuel switching. Consequently, while analyzing the fuel switching price effect implicitly by including the gas and coal price, or explicitly by calculating the price like it is done for example by Alberola et al. (2008) or Creti et al. (2012), it may be the case that this fuel price only applies to certain areas of Europe. Not surprisingly, market observers and researchers like CDC climate research or Point Carbon publish different fuel switching prices, for e.g. Germany or the UK.

The issue of regional variation in prices is even more pronounced for electricity prices, which show an even lower correlation than gas or spot prices (Bobinaitė et al. 2006). Consequently, explaining EUA price variation by including a regional electricity price, as done for example by Alberola et al. (2008), might result in spurious results. Additionally, including the electricity price might also weaken the theoretical foundation because there seems to be a two-way relationship between electricity price and EUA price as indicated by Bunn and Fezzi (2008) and Fell (2010) who both account for the regional scope of the various electricity prices by analyzing the market in the UK and in the Nordic countries, respectively. When including the electricity price, the EUA price thus cannot be treated as the only endogenous variable. While Bredin and Muckley (2011) confirm that a long-term relationship between the electricity price and the EUA price established during Phase II[9], this result should be interpreted with caution because their analysis is not restricted to a regional electricity market and might therefore not be an indication for a long-term relationship in the EU ETS. This caveat does not apply for the study of Creti et al. (2012). While Rickels et al. (2007) and Hintermann (2010) do not find any cointegration between EUA prices and fuel prices, Creti et al. (2007) show that, in Phase II, such a stable long-term relationship between the price series emerges. This is meaningful in the sense that determinants of marginal abatement costs and demand fluctuations are reflected. This is surprising because the market regained its long position already in the middle of Phase II implying that there is no need for further abatement and therefore the equilibrium price for EUAs could approach zero as there is no scarcity in allowances.

---

[7] Hintermann(2010) does not include the oil price.

[8] Hintermann uses the McCloskey North Weasten Steam Coal Marker, Mansanet-Bataller et al. and Alberola et al. use future prices which are settled against the API2 CIF ARA coal index. This price index summarizes the North Weastern Steam Coal Marker Index and expert assessment based on statements of individual traders. In contrast, Rickels et al. (2007) use the API 4 price index measuring the coal price at Richards Bay. Nevertheless, both Rickels et al. and Alberola et al. find a negative influence of the coal price, whereas Mansanet-Bataller et al. and Hintermann do not.

[9] Bredin and Muckley (2011) implicitly include the electricity price by using the dark and spark spread as explanatory variables. The dark (spark) spread is the difference between the electricity price and the power generation cost using coal (gas) as input fuel.

All studies find evidence of the influence of extreme weather events (see also Ellerman et al. 2010 for details), but following different approaches for capturing the nonlinear relationship between temperature and energy demand. Mansanet-Bataller et al. (2007) and Alberola et al. (2008) construct dummy variables for extremely hot and cold days, Rickels et al. (2007) and Hinterman (2010) use the deviation on extremely hot and cold days from the longtime average. Additionally, Alberola et al. (2008) also include interactions of dummy variables for extreme weather events and the deviations from their longtime averages. Hintermann (2010) includes weather variables in a nonlinear manner by using interactions of weather variables and fuel prices.

The discrepancy between the price predicted by theory and the price observed in reality might be explained by factoring in uncertainty, which is dealt with in a second strand of literature. Compliance with the emission cap is not only determined by current emissions but by cumulative emissions and therefore total expected emissions might serve as a good indicator for the EUA spot price (Seifert et al. 2008). The current and cumulated emissions of a firm might follow to a certain extend a stochastic process due to for example unforeseen demand variations, so that the firm has to form expectations on the spot price at the end of the period. Consequently, holding a EUA allows either using it for compliance, selling it at the end of the period, or retire it if the cap turns out to be non-binding. It therefore provides an option value for the holder (e.g., Chao and Wilson 1993; Chesney and Taschini 2012; Hintermann 2012). As already pointed out by Chao and Wilson (1993) the holding of an emission allowance increases the flexibility to adapt to market conditions so that the allowance price exceeds the marginal abatement costs by the option value. The option value is increasing in the irreversibility of investment in abatement and the uncertainty about future market conditions (Chao and Wilson 1993). With respect to uncertainty about future market conditions, it needs to be taken into account that any news about those conditions require a new optimization, thereby increasing not only the probability of price jumps but obviously also the value of greater flexibility in holding options in terms of EUAs (Schennach 2000). Taking these uncertainties into account, the price path of will never approach zero before the end of the trading period as long as a positive probability of exceeding the cap remains (Seifert et al. 2008; Chesney and Taschini 2012). However, if the future probability of a shortfall in permits becomes sufficiently low the price converges to zero as observed at the end of Phase I. In line with these considerations Carmona et al. (2009) show in a numerical simulation that allowance prices are only a poor indicator of marginal abatement costs. These theoretical aspects have, to our knowledge, only been empirically investigated by Hintermann (2012) so far. His results show that an option-value approach of holding emission allowances seems to describe the price dynamics in Phase I much better than the equalization of marginal abatement costs described above. Consequently, the results suggest that firms hold EUAs to hedge against the possibility to pay the penalty.

The value of holding EUAs from an option or hedging perspective might even increase if one takes into transactions costs of trading. Heindl (2012) shows based on survey data that transactions costs matter in particular for small firms, while they decrease for firms emitting more than one million tons CO_2. He estimates that small firms have to bear about one additional Euro per ton traded so that it might be favorable for them not to actively engage in trading. This assessment is supported by further survey data, indicating that in Germany only about 51 and 54 percent of firms under the EU ETS were involved in trading in 2009 and 2010, respectively (Heindl und Löschel 2012). Additionally, from those firms involved in trading, about two-third traded only once a year. Even though these numbers might be not representative for the entire EU ETS because large firms representing the majority of carbon emissions might still ensure active trading on the market, it seems that a significant fraction of EU ETS participants follows the hold and see strategy discovered by Hintermann (2012) in the data on Phase I.

Finally, it should be stressed that this "option value" strand of the literature, which treats emissions as stochastic and does not or only to a limited extend consider abatement, assumes the same influence of overall energy or electricity consumption and provision of renewable energy on allowance prices as derived in under the assumption of equalization of marginal abatement costs in Section 2.1

Additionally to the two strands of literature discussed so far there are several further papers investigating aspects related to the EU ETS. One prominent strand that can be summarized under the term carbon finance also focusses on the uncertainty and volatility of carbon prices. For example, Benz and Trück (2009) investigate the stylized facts of EUA price series showing that they are characterized by volatility clustering and can be therefore be described by regime switching models. They show that GARCH models are suitable to deal with the heteroscedasticity and unconditional tail distribution in EUA price series, as it was previously shown by Paolella and Taschini (2008) and confirmed by Chevallier (2011), Feng et al. (2011), or Conrad et al. (2012). The study of Conrad et al. (2012) applies high-frequency intra-day data and shows that policy news like the decisions of the European Emission on allocated allowances in member countries has strong and immediate impacts on EU prices. They also show a positive influence of prices on growth announcement in Germany or the US. This becomes also evident in the study of Chevallier (2011) who extends the work of Benz and Tück by applying regime switching models but using monthly average data on EUA prices and influence factors. Borak et al. (2006) investigate the pattern of the EU ETS market by focusing on the term structure between future and spot prices of allowances and their stochastic properties. Their findings imply that the EUA market was in its early period not liquid or efficient. Daskalakis and Markellos (2008) and Daskalakis et al. (2009) confirm the stochastic behavior of EUA prices by approximating it with a Geometric Brownian Motion augmented by jumps and show by investigating the relationship between spot and future prices that restrictions on banking between phases implies additional uncertainty and costs in hedging. Montagnoli and Vries (2010) address the issue of thin trading and conclude that the EU ETS was inefficient in Phase I, but efficient during the first period of Phase II (until April 2009). Besides the carbon finance literature there are further papers investigating for example the price spread between EUAs and carbon credits from abroad or the impact of EUA prices on stock returns of electricity companies (Mansanet-Bataller et al. 2011; Oberndorfer 2009). A still very good and comprehensive overview is provided by Zhang und Wei (2010).

In summary, existing studies revealed that fundamentals reflecting marginal abatement costs had only a limited influence on the EUA price dynamics in Phase I whereas policy announcement and news were responsible for a significant fraction of fluctuations. An analysis of price determinants against the background of marginal abatement equalization during this phase may thus not be reliable. Assuming no active abatement while holding EUAs as a hedging strategy against non-compliance penalty seems to be the better approach to explain price dynamics during Phase I. The more recent studies using also data from Phase II (until December 2010) show that the equalization of marginal abatement costs approach seems to regain momentum. Against this background, our contribution to the literature is threefold. First, our analysis is based on longer time-series data for Phase II (until July 2012). Second, our analysis applies an extensive set of EUA, coal and gas prices to highlight the importance of choosing a specific series among the various available. Third, our analysis includes an extensive set of renewable energy provision and test for the significance of the various variables in simple single-equation settings. Based on the comprehensive data selection we test whether an economically meaningful long-run relationship exists and estimate the corresponding vector error correction models and single-equation models.

3. Data Selection and Analysis

Against the background of section 2.2., we now discuss and analyze available data. In contrast to the literature, we consider several price series for, e.g., the coal price because we believe that there is sufficient uncertainty about the actual prices, which power producers face in their optimization problem.

3.1 EU Emission Allowances

EUA Emission Allowances are traded over-the-counter (OTC) and on spot and future markets. Whereas OTC trades are mainly operated by brokers, spot and future trades take place on several stock exchanges. Prominent stock exchanges across Europe are the Intercontinental Exchange (ICE) Futures Europe, the European Energy Exchange (EEX) in Leipzig, Germany or the NASDAQ OMX Commodities Europe in Oslo (formally called Nordpool). Additionally, EUA spot and future trades take place on international stock exchanges like GreenX Exchange listed on the GME Globex electronic platform or BlueNext. Point Carbon provides information on aggregated traded volumes from 01.12.2004 onwards and from 10.06.2009 onwards also information on disaggregated traded volumes in the OTC and stock market.

Table 1 shows that while Bluenext accounted at least for the majority of spot trade in Phase I of the EU ETS ICE has become the leading market in Phase II. GreenX started operating in 2011 and became the second largest exchange in 2011. In 2012 there are probably data problems since a trading volume of zero was reported for a large set of days. Additionally, Table 1 shows that in Phase II trade via the exchange has become the most liquid market while in Phase I this was claimed for the OTC market (Alberola et al. 2008).

Table 1: Average daily volumes, 10.06.2009 to 31.07.2012 for OTC and spot/future trades (in kt)

	2009		2010		2011		2012	
	exchange	OTC[a]	exchange	OTC[a]	exchange	OTC[a]	exchange	OTC[a]
ICE[b]/ECX[c]	6971.17	7169.18	11904.83	5491.32	15070.15	6301.31	16066.63	6738.48
EEX[d]	115.27	1.73	434.09	0	238.76	0.04	266.00	0
Nordpool	70.32	0	72.19	0	27.59	0	216.37	0
GreenX	0	0	0	0	417.72	1006.65	32.71	945.30
Bluenext	2056.99	248.84	906.55	143.74	160.74	21.77	93.46	40.38

[a]over-the-counter; [b] Intercontinental Exchange; [c] European Climate Exchange; [d]European Energy Exchange

Accordingly, previous studies use price data from BlueNext (e.g., Daskalakis et al. 2009; Alberola et al. 2008) or price data from OTC trades (e.g., Benz and Trück 2009; Hintermann 2010, Hintermann 2012).[10] Recent studies extending into Phase II use prices of EUA futures from the ICE (e.g., Bredin and Muckley 2011; Conrad et al. 2012; Creti et al. 2012). ICE price data are also used in regular market reports like the Carbon Market Daily by Point Carbon (Allan et al. 2012) or the Tendances Carbone monthly bulletin on the European Carbon Market (Stephan 2012). One exemption is the pioneering study by Mansanet-Bataller et al. (2007) that used the Carbix Index by the EEX which was named at that time the European Carbon Index (see EEX 2012 for details).

---

[10] Benz and Trück obtained OTC price series from Marex Spectron, a privately owned broker company and Hintermann obtained OTC price series from Point Carbon.

Table 2: Overview about EUA prices in Phase II

	Data Availability	Discontinuities[a]			
ICE Fut Dec12[b]	02.01.2008-20.07.2012	-			
ICE RFut Dec0812[c]	02.01.2008-20.07.2012	-			
Nordpool Fut Dec12[d]	02.01.2008-20.07.2012	-			
PC OTC Fut Dec12[e]	02.01.2008-20.07.2012	-			
PC OTC RFut Dec0812[f]	02.01.2008-20.07.2012	-			
EEX Carbix[g]	25.03.2008-12.06.2012	-			
BlueNextSpot	26.02.2008-20.07.2012	20.01.11-03.02.11;03.11.11-11.11.11; 01.06.12-20.06.11			
	2008				
	Mean	Standard Deviation	Coef. Variation	Min	Max
ICE Fut Dec12[b]	25,73	4.02	0,16	16,38	34,38
ICE RFut Dec0812[c]	22,40	3.54	0,16	13,72	29,33
Nordpool Fut Dec12[d]	22,56	3.34	0,15	14,40	28,75
PC OTC Fut Dec12[e]	25,74	4,04	0,16	16,22	34,35
PC OTC RFut Dec0812[f]	22,44	3,50	0,16	14,16	29,38
EEX Carbix[g]	22,38	3,81	0,17	13,80	29,30
BlueNextSpot	22,33	3.73	0,17	13,70	28,73
	2009				
ICE Fut Dec12[b]	15,31	1,71	0,11	9,43	18,37
ICE RFut Dec0812[c]	13,36	1,54	0,12	8,20	15,87
Nordpool Fut Dec12[d]	13,31	1,58	0,12	8,00	15,70
PC OTC Fut Dec12[e]	15,29	1,71	0,11	9,45	18,25
PC OTC RFut Dec0812[f]	13,35	1,55	0,12	8,20	15,78
EEX Carbix[g]	13,21	1,59	0,12	8,02	15,37
BlueNextSpot	13,15	1,57	0,12	7,96	15,49
	2010				
ICE Fut Dec12[b]	15,42	0,90	0,06	13,53	17,68
ICE RFut Dec0812[c]	14,47	0,98	0,07	12,41	16,52
Nordpool Fut Dec12[d]	14,47	1,01	0,07	12,20	16,45
PC OTC Fut Dec12[e]	15,41	0,90	0,06	13,58	17,66
PC OTC RFut Dec0812[f]	14,48	0,98	0,07	12,45	16,50
EEX Carbix[g]	14,35	1,01	0,07	12,04	16,16
BlueNextSpot	14,35	1,00	0,07	12,17	16,29
	2011				
ICE Fut Dec12[b]	13,83	3,18	0,23	6,86	18,27
ICE RFut Dec0812[c]	13,26	3,04	0,23	6,45	17,42
Nordpool Fut Dec12[d]	13,29	3,00	0,23	6,88	17,44
PC OTC Fut Dec12[e]	13,84	3,18	0,23	6,84	18,21
PC OTC RFut Dec0812[f]	13,28	3,00	0,23	6,84	17,36
EEX Carbix[g]	12,97	2,89	0,22	6,50	16,90
BlueNextSpot	13,02	2,91	0,22	6,47	16,93
	2012				
ICE Fut Dec12[b]	7,50	0,78	0,10	6,21	9,51
ICE RFut Dec0812[c]	7,50	0,78	0,10	6,21	9,51
Nordpool Fut Dec12[d]	7,50	0,79	0,11	6,25	9,51
PC OTC Fut Dec12[e]	7,48	0,79	0,11	6,09	9,48
PC OTC RFut Dec0812[f]	7,48	0,79	0,11	6,09	9,48
EEX Carbix[g]	7,29	0,83	0,11	6,02	9,43
BlueNextSpot	7,39	0,78	0,11	6,04	9,27

[a] Only discontinuities longer than one day are mentioned[b] Intercontinental Exchange future prices with maturity at the end of Phase II [c] Intercontinental Exchange rolling futures with maturity at the end of the year [d] Nordpool future prices with maturity at the end of Phase II [e] Point Carbon over-the-counter future [f] Point Carbon over-the-counter rolling future [g] European Energy Exchange Carbon Index

In order to see whether the chosen price makes a difference we start by comparing future prices negotiated at exchanges or OTC as well as spot prices. We consider both future prices with maturity at the end of Phase II (Fut Dec12) and rolling futures with maturity at the end of the year implying that, in December, the maturity switches to the following year (RFut Dec0812). Table 2 provides descriptive statistics for Phase II future prices from ICE and NASDAQ OMX (Nordpool), future prices from OTC trade reported by Point Carbon, the Carbix reported by the EEX, and spot prices from the BlueNext. We could not obtain price series from GreenX. Note also that only future price series from ICE, PC, and Nordpool extend over the whole investigation horizon.

The highest EUA prices (on average around 22 to 26 EUR per tCO_2) were observed in 2008. Prices then decreased in 2009 (to on average 13 to 15 EUR per tCO_2) and stabilized until the end of 2010. 2011 shows much higher variation than in the previous years, especially 2010. Prices also started to decrease slightly – a trend that gained momentum in 2012, when prices by end of July were on only about 7.5 EUR per tCO_2. Comparing FutDec12 and the rolling future (RollFut) shows that prices tend to be lower at the end of the maturity. Consequently, differences between the two prices series decreases over the course of Phase II. In 2012, both price series are basically identical. Finally, we only observe very minor differences between future prices negotiated on the exchange and OTC.

We carry out a correlation analysis following Mansanet-Bataller et al. (2007). For detailed results on correlation in levels and differences see table A.1 in the appendix. As expected, there is a very high correlation between prices in levels. The lowest correlation is found for the Carbix (less than 0.84) to the other prices. However, all these prices series are not stationary, so that a regression analysis (except for cointegration analysis – see section 4) is normally based on First Differences or Log-Differences. Looking at the correlation in log-differences, the future price series are still highly correlated (>0.81), however, this does not any longer hold for the spot price (BlueNext) or the Carbix. Consequently, we see that already the selection the dependent carbon price series will have a significant influence on the results.

Relying on the trading volumes, the continuity of the price series and its dominant application in the literature, we will in our analysis also use EUA future price series from the ICE, choosing the rolling future price series.

3.2 Fuel Switching: Coal and Gas Prices

As explained in Section 2 the prices for coal and gas are expected to influence the EUA price due to the short-term possibilities of fuel switching. In this section we analyze – based on a correlation analysis – in how far different existing coal, gas and derived fuel switching prices differ from each other and try to derive the price series with the highest explanatory power for the EUA price.

Why we believe that the choice of a certain price series is important can be explained, when e.g. looking at coal prices. Most studies on the determinants of the EUA price rely on a coal price closely related on the Argus/McCloskey's Coal Price API2 CIF ARA[11] (e.g., Mansanet-Bataller et al. 2007; Hintermann 2010;

---

[11] CIF refers to costs, insurance and freight; ARA means that the coal is delivered to the Amsterdam-Rotterdam-Antwerp region. Further information on the API 2 Index can be found under http://www.argusmedia.com/Methodology-and-Reference/Key-Benchmarks/API-2.

Bredin and Muckley 2011; Creti et al. 2012), which is often regarded as the primary reference coal price for northwest Europe.[12] But the EU

ETS countries import coal from all over the world and it is likely that prices for each single trade differ significantly.[13] In fact, it has been argued that the coal market is characterized by a significant lack of transparency and segmentation so that no unique coal price exists (Zaklan et al. 2012). Even though it is true that almost all coal derivatives are priced and settled against the API2 and API4 price index (Schernikau 2010), Zaklan et al. (2012) point out that steam coal is not a standardized commodity because it varies with respect to its heat value or moisture content. While ICE-traded future contracts, which are priced against the API2, are standardized with respect to the heat value, this is probably not the case for the various OTC trades. Furthermore, Schernikau (2010) calls the reliability of the API2 index into question because he observed that "it has been impossible to buy physically delivered coal in Europe at prevailing API2 prices" between 2006 and 2008 (p. 156). He shows that there is a significant gap between the API2 price series, which implies CIF delivery to the Amsterdam-Rotterdam-Antwerp (ARA) region, and the coal price FOB at Richards Bay (API4) plus the prevailing freight rate, and that this price gap could not be explained by market participants. Consequently, Zaklan et al. (2012) emphasize that even though the coal market "is gradually moving from a segmented OTC dominated activity to a higher degree of […] international integration, a truly integrated single-world coal market has yet to be achieved" (p. 106). Accordingly, it is unlikely that we can choose the correct coal price faced by power utilities when they decide on fuel switching. This concern is amplified by the fact that we are unable to choose the correct maturity of future prices because we do not know anything about the timing of fuel switching decisions.

Tables A.2 and A.3 in the appendix show descriptive statistics for various coal and gas prices. All prices are transformed to EUR/Mwh, where we implicitly assume a plant efficiency of 1 in the transformation due to a lack of detailed information. Since the average efficiency e.g. in steam coal power plants is normally below 0.5, the prices are measured in "theoretical", not "real" Mwh units. Table A.2 shows that coal prices peaked in 2008, dropped in 2009, and recovered slightly in the following years. Furthermore, longer maturities tend to be more expensive. Coal prices in Richards Bay (API4) are lower since these prices are FOB, in contrast to CIF for API2. As Table A.3 shows that also gas prices where highest in 2008 than dropped in 2009 and slightly recovered in the following years. It is not obvious that one price series is significantly lower than others.

To analyze whether the price series follow a common trend (which seems to be the case at least for coal prices – see also Warrel 2006; Li et al. 2010; Zaklan et al. 2012) we calculate correlations in levels and log differences (see Tables A.4 to A.6 in the appendix). According with existing literature, the various coal price levels are almost perfectly correlated while looking at the correlation in log differences paints a different picture: in particular the ICE API2 CIF ARA Index is relatively weakly correlated with the other price series (0.15<rho<0.66). For gas, already the correlation in levels is lower, though mostly still above 0.8). It is only the ICEUK 1S index that has a lower correlation with most other price series. Correlation in log differences is even lower than for coal. Here in particular the APX TTF IND Index and the ICE UK 1S

---

[12] Hintermann uses the McCloskey's northwest European steam coal marker, which is also used to calculate the API2 Index. Bredin and Muckley use the clean dark and spark spread which is calculated by the Caisse des Depots Climate Task Force for Tendances Carbone based on the API 2 index.

[13] For example, Germany imported about 42 Mt of hard coal in 2011, of which 25 percent came from Columbia, 24 percent from Russia, 23 percent from the US and Canada, 10 percent from Australia, 9 percent from Poland, and 6 percent from South Africa (Eurostat); all at different prices.

Index are relatively weakly correlated with the other price series ($0.05 < \text{rho} < 0.69$). Consequently, the various coal and gas prices might explain different aspects of the variation in the EUA prices.

To deal with this problem we run a simple regression with EUA prices explained by a constant and use the residual series to investigate the influence of the possible prices following Herwartz (2010). This allows us to detect which fuel price series explains most of the EUA price variations. Herwartz (2010) suggested to iteratively repeat this procedure until the explanation of variation fails to meet a certain selection criteria based on a LM statistic. Yet, as EUA price series show significant heteroscedasticity the LM-statistic obtained from such an auxiliary regression might be no longer exact. However, as for example the coal price should only be represented by one price series, the maximum explanation of variation is a sufficient selection criterion. The results of the auxiliary regression for the influence of the coal and gas prices are shown in Table 3 where we use Newey-West based determination for the coefficient covariance matrix to deal with heteroskedasticity in the data.

As Table 3 shows an increase in coal prices is in most cases associated with an increase in EUA prices. In two cases, the effect is insignificant, yet with a positive point estimate. These outcomes clearly contradict economic theory because higher coal prices should, in principle, divert power utilities into using fuels with lower carbon content and hence result in decreasing EUA prices. Our guiding principles for variable selection would require us to pick the coal price with the highest explanatory power, i.e. the DL ICE API2 RO 1S (1-season ahead, Rotterdam, priced against API2, traded on ICE). Yet, since this relationship contradicts economic theory, we additionally pick the DL ICE API2 ARA Ind because its relationship with EUA prices is insignificant and thus not contradicting theory.[14]

For gas prices, the series with significant influence are in line with economic theory. However, we observe a difference in the influence of the maturity between the German and the UK gas market. Whereas for both delivery points in Germany, Gaspool and NCG, the degree of explained variation in the EUA price increases with maturity, the opposite is true for the UK market. Here, the degree of explained variation decreases with maturity and the future price series for one season ahead is even insignificant in its influence on the EUA price variation. This shows that there are difference in the German and the UK gas market. Consequently, the auxiliary regression suggests using the future gas price series negotiated at the EEX with delivery in the Gaspool net one year ahead for explaining the EUA prices (EEX Gaspool 1Y). We also use the future gas price series with maturity one month and delivery at the national balancing point in the UK (ICE UK 1M) to account for possible differences between the continental and UK gas market.

Now we turn to the fuel switching price which indicates the theoretical EUA price that makes power producers indifferent between coal and gas based power production. In line with the theoretical derivation of the fuel switching price in Section 2.1 we use the following formula (Tendance Carbon 2007):

$$fs = \frac{h_{gas} * P_{gas} - h_{coal} * P_{coal}}{e_{coal} - e_{gas}} \qquad (1)$$

where P_i represents the fuel price, h_i the inverse of the heating rate, and e_i the emission factor. Note that no unique fuel switching price exists. As already pointed out, the gas market shows regional variation between Germany and the UK. Consequently, power companies in Germany and UK face different fuel switching prices and accordingly in market reports like the one by Tendances Carbone fuel switching prices are

---

[14] According to the literature, the ICE API2 ARA Ind also reflects the European coal price best.

calculated for the UK and Germany (Tendances Carbon 2012). Moreover, the fuel switching price varies with different assumptions about the heating rate which indicates how much of the theoretical energy can be converted into power. Point Carbon e.g. reports three different fuel switching prices with different assumptions about the transformation efficiency (see ww.pointcarbon.com).[15]

Table 3: Single-equation influence of various coal and gas prices on the residual series EUA rolling future

	Coefficient	t-value (Newey-West)	R^2
Coal Prices			
DL[a] EEX API2 ARA 1M[b]	0.243817	6.2332***	0.031367
DL EEX API2 ARA 1Q[c]	0.268541	6.7066***	0.037856
DL EEX API2 ARA 1Y[d]	0.313997	5.9900***	0.039907
DL ICE API2 RO[e] 1M	0.298448	7.3524***	0.042470
DL ICE API2 RO 1Q	0.318023	7.3259***	0.043232
DL ICE API2 RO 1S[f]	**0.368111**	**7.8056*****	**0.058996**
DL ICE API2 ARA Ind[g]	**0.053759**	**1.2856**	**0.001695**
DL EEX API4 RB[h] 1M	0.234757	5.8066***	0.031248
DL EEX API4 RB 1Q	0.270587	6.5613***	0.040723
DL EEX API4 RB 1Y	0.321082	6.2154***	0.045555
DL NYMEX[i] 1M	0.093540	2.2264**	0.005085
DL MC NEW Price[j]	0.022685	0.5631	0.000314
Gas Prices			
DLog[a] APX TTF ind[k]	-0.013042	-0.7007	0.000366
DLog EEX Gaspool 1Q	0.188432	3.6266***	0.038054
DLog EEX Gaspool 1Y	**0.353732**	**2.9150*****	**0.064860**
DLog EEX NCG_1Q[l]	0.183847	3.4165***	0.037278
DLog EEX NCG_1Y	0.350814	2.9490***	0.063115
DLog ICE UK[m] 1M	**0.132807**	**4.1474*****	**0.027525**
DLog ICE UK 1Q	0.061501	2.3547**	0.005330
DLog ICE UK 1S	0.018328	1.3485	0.000768

[a] Log-difference [b] European Energy Exchange ARGUS Coal American Petroleum Institute (API) 2 Cost Insurance and Freight (CIF) Amsterdam Rotterdam Antwerp (ARA) Daily Index Contract 1 Month [c] 1 Quarter [d] 1 Year [e] Rotterdam [f] 1-season ahead [g] ARGUS Coal American Petroleum Institute (API) 2 Cost Insurance and Freight (CIF) Amsterdam Rotterdam Antwerp (ARA) Daily Index Contract [h] Coal price at Richards Bay [I] New York Mercantile Exchange [j] McCloskey NWE Steam Coal Marker Price
[k] APX-ENDEX Title Transfer Facility Index [l] European Energy Exchange Net Connect Germany [m] United Kingdom

Source: Own calculation

The fuel switching price provides valuable information for understanding the carbon market because observing a difference between this price and the actual EUA price could allow drawing conclusion on the prevalence of fuel switching and on the actual efficiency in power plants. Following Creti et al. (2012) we calculate four fuel switching prices from the selected gas and coal prices and assume identical heating rates and emission factors.[16] Additionally, we include the UK fuel switching price based on front summer

---

[15] Point Carbon calculates an average, high and low fuel price scenario, assuming coal and gas plant efficiencies of 0.36 and 0.50 (average), 0.40 and 0.46 (high), and 0.34 and 0.56 (low), respectively.

[16] The plant efficiency or the inverse of the heating rate and the emission factors are: h_{coal}=0.36, h_{gas}=0.5, e_{coal}=0.86, and e_{gas}=0.36.

contracts provided by Point Carbon from December 30th, 2008 onwards based on average heating rates. Again we calculate correlations for these time series (see Table A.6 in the Appendix) which show a similar picture as for coal and gas prices: in levels there is a high correlation that is significantly reduced in log differences. This can also be illustrated visually in Figure 1 that shows the price series for the fuel switching price obtained from Point Carbon and the calculated fuel switching prices based on the gas prices either from ICE one month ahead with delivery to Rotterdam or from EEX one year ahead with delivery to Gaspool and the coal price from the ICE one season ahead with delivery to Rotterdam. Note that we do not show the two remaining fuel prices which result from combining the two gas prices with the coal price from the ICE API2 CIF ARA as there are only marginal differences to the price series with the first coal price.

We see that there are significant differences in the price series. Differences in levels between the fuel switching price from Point Carbon and our calculated prices can partly be explained by different assumptions about the plant efficiency. However, such differences in levels should not affect the results as explained above. More interestingly the figure indicates that there are obvious differences in volatility and curvature. This confirms one more that your results will be again quite sensitive to the price series chosen. Like with the coal and gas price series we also run auxiliary regressions on the residual of EUA prices with the various fuel switching prices and the results are shown in Table 4.

Figure 1: Implied fuel switching price from 30.12.2008 until 20.07.2012

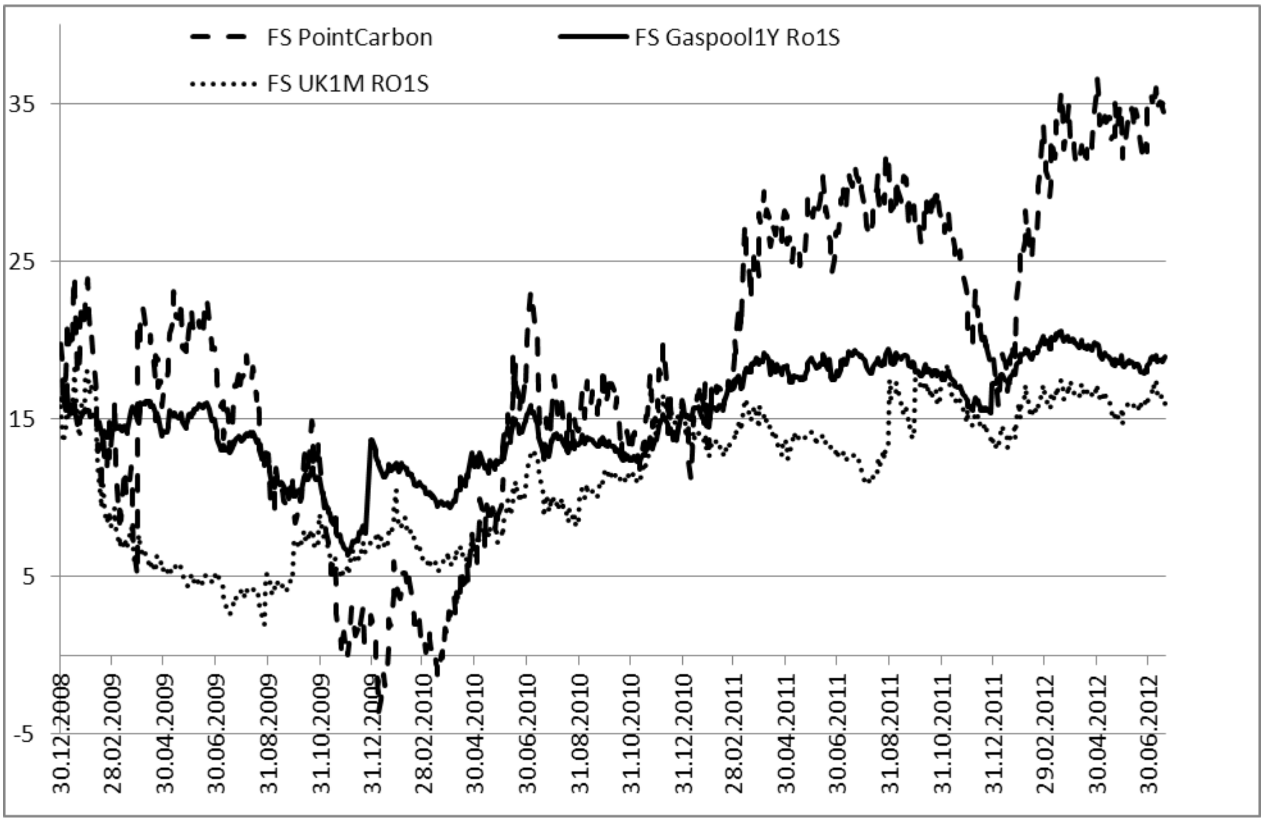

Table 4: Single-equation influence of various fuel switching prices on the residual series EUA rolling future Dec0812 price series (in log-differences)

Fuel Switching Prices (Gas price and coal price)	Coefficient	OLS t-value (Newey-West)	R2
Fuel Switching Prices (Gas price and coal price)	0.1996**	2.2892	0.0390
EEX Gas Gaspool 1Y[b] and ICE Coal Ro 1S[c]	**0.2412*** **	**2.7761**	**0.0608**
EEX Gas Gaspool 1Y and ICE Coal ARA API2[d]	0.0476***	2.7097	0.0111
ICE GAS UK[e] 1M and ICE Coal Ro 1S	0.0194***	3.1642	0.0194
ICE GAS UK[e] 1M and ICE Coal ARA API2 [d]	0.0107**	2.5565	0.0084

[a] Source: Own calculation [b] European Energy Exchange Gaspool 1 Year [c] Intercontinental Exchange Coal Rotterdam 1-season ahead [d] Intercontinental Exchange Coal ARGUS Coal American Petroleum Institute (API) 2 Cost Insurance and Freight (CIF) Amsterdam Rotterdam Antwerp (ARA) Daily Index Contract [e] United Kingdom

We see that all switching prices have the expected sign, indicating that the combined influence of both prices leads to fuel switching. The largest fraction of variation is explained by the fuel price resulting from the price for gas delivered to the Gaspool net, negotiated one year ahead at the EEX and the API2 Coal Price, negotiated at the ICE. Note that this coal price was insignificant in the single equation estimation (Table 3). We already discussed that therefore this price seems to be closest to economic theory which seems to be confirmed by the results with the fuel switching price. However, the gas prices used in the fuel switching price explained a larger fraction of variation in their single equation estimation (see Table 3) than in combination with the coal prices. Therefore, it is not surprising that the fuel switching price with the insignificant coal price has the largest R^2 because this coal prices dampens their explanatory power only marginally.

3.3 Energy consumption: Economic Activity and Renewable Energy

Economic activity is an important determinant of energy consumption and, hence, also for carbon emissions. In order to capture the influence of economic activity on the EUA price, we include (1) an equity index, also capturing general market disturbances such as the financial crisis (Creti et al. 2012), and (2) the oil price, serving as a further indicator for economic activity. Even though we do not expect an influence of the oil price on EUA prices due to fuel switching (because the fraction of oil-based power generation is very small), most other authors have also included the oil price either as indicator for economic activity or for the future gas price. As equity index we take the Dow Jones Euro Stoxx 50[17] and as oil price the ICE Brent future price index (see Bredin and Muckley 2011; Creti et al. 2012 for both).[18]

Apart from economic activity, energy consumption is also affected by weather conditions, in particular temperatures. The relationship between temperature and energy demand is nonlinear (u-shaped) (Boudoukh et al. 2007; Bunn and Fezzi 2008): cold winter days increase the demand for heating and hot summer days are associated with more intense use of air condition. Normal levels and variations in temperatures, and hence in energy demand, are expected beforehand, so that they are taken into account in the production plans of utilities and are covered by allotted EUAs. Consequently, daily variation in EUA prices should only be affected by extreme deviations from the expected values. Previous studies have implemented this idea by constructing dummies for extremely hot and extremely cold days, but came to mixed conclusions

---

[17] The Dow Jones Euro Stoxx 50 is considered to be Europe's leading stock index comprising the 50 largest European countries.

[18] The two series have low correlation (0.1693), but show some similarities in their volatility patterns and accordingly have in log-differences a correlation of 0.3387.

about the magnitude of impact (cf. Mansanet-Bataller 2008; Alberola 2008; Rickels et al. 2007; Hintermann 2010).

Instead of constructing approximate measures for energy consumption based on extreme temperatures, we follow Hintermann (2012) and use data on load values. The data are provided by the European Network of Transmission System Operators for Electricity (entsoe). [19] Importantly, load values do not exactly correspond with consumption data: load values are measured at one point in time (e.g. in MW), while consumption is measured over a period of time (e.g. in MWh). Yet, we consider load values to be a valid proxy for consumption measured because the values provided by entsoe are average values for one hour. Our data range from 01.01.2008 until 30.04.2012 and include Austria, Czech Republic, Germany, Spain, France, and Italy. Naturally, the data series shows a significant seasonal pattern. In order to smooth the series, we regress the aggregated log load values on a constant and three season dummies, and henceforth use the residual series of this regression. Table 5 provides the results of the auxiliary regression on the residuals of EUA prices.

Table 5: Single-equation influence of Eurostoxx50, oil price and load values on residual of EUA prices (in log-differences except load values for Europe).

	Coefficient	OLS t-value (Newey-West)	R2
DJ[a] Euro Stoxx 50	0.4185	9.6211***	0.0838
ICE[b] oil brent future price 1M[c]	0.2321	6.2101***	0.0411
Load values for major European countries	-0.0097	-0.8041	0.0005

[a] Dow-Jones [b] Intercontinental Exchange [c] 1-month future

Source: Own calculation

Table 5 shows the individual influence of our proxies for energy demand on EUA prices. Both the DJ Eurostoxx 50 and the oil price have a significant positive influence on EUA price dynamics, which is in line with economic theory. The seasonality-adjusted load values do not have a significant influence on the EUA prices.[20] The DJ Eurostoxx 50 alone already explains a rather significant part of the variation in EUA prices.

As explained in Section 2, weather conditions do not only influence energy demand but also energy provision because the generation of hydro, wind, and solar power depend on precipitation, wind speed, and irradiation, respectively. In order to account for this impact we collected data on the daily renewable feed-in across Europe. Table 6 provides an overview about our data sources, country coverage, and time periods. It should be noted that the inclusion of data on solar energy (from Spain. Italy, and Germany) was not possible because the available time series do not cover the entire period of analysis.

---

[19] https://www.entsoe.eu/resources/data-portal/consumption/

[20] The insignificant result might be due to the aggregation of various countries and the resulting smoothening of some load peaks.

Table 6: Source and time periods of data on renewable energy feed-in

Germany	
Wind	01.01.2008 -19.07.2012
Source: European Energy Exchange, http://www.transparency.eex.com/en/	
Denmark	
Wind	01.01.2008-25.06.2012
Source: Energinet –DK, http://energinet.dk/EN/El/Engrosmarked/Udtraek-af-markedsdata/Sider/default.aspx	
Sweden	
Wind	01.01.2008-30.04.2012
Hydro	01.01.2008-30.04.2012
Source: Svenska Kraftnät, http://www.svk.se/energimarknaden/el/Statistik/Elstatistik-for-hela-Sverige/	
France	
Hydro	01.01.2008-04.07.2012
Source: RTE, http://clients.rte-france.com/lang/an/visiteurs/vie/prod/realisation_production.jsp	
Norway[a]	
Hydro	04.01.2010-19.07.2010
Source: Nordpool, http://www.nordpoolspot.com/Market-data1/Power-system-data/Production1/Production1/ALL1/Hourly1/	

[a] We did not obtain actual information on hydropower generation from Norway but used daily generation of power as proxy because about 99 percent of Norway’s total power production is generated by hydropower (see http://www.regjeringen.no/en/dep/oed/Subject/Energy-in-Norway/Electricity-generation.html?id=440487).

Again, we estimated simple regressions of the log daily feed-in of renewable energy on the residuals of EUA prices in order to check for their individual impact on prices. We also used both the deviation from the mean feed-in and dummies indicating whether the realization lies in the highest or lowest decile. Apart from effects from (i) low wind power provision in Sweden and (ii) low hydro power provision in France, renewable energy provision did not have any significant influence on EUA prices.

In addition to the daily renewable feed-in, we included data on reservoir levels in Norway, France, and Spain. The data are expressed as current filling relative to maximum capacity. Again, we use the residuals from a regression with a constant and season dummies. The results show that only the relative share of reservoir levels in Norway has a significant influence on EUA price dynamics (see Table X).

Table 7: Single-equation estimation with seasonal adjusted reservoir level filling shares on residual of logarithmic EUA prices

	Coefficient	OLS t-value (Newey-West)	R2
Norway	-0.0480	-2.4570***	0.0168
France	-0.0020	-0.04454	0.0000
Spain	0.0074	0.2664	0.0003

Source: Own calculations

Note: With the exception of Spain, these data are only available on a weekly basis and accordingly we test their influence on average weekly EUA prices.

4. Empirical influence of fundamental determinants on EUA prices

An important aspect to understanding the EU ETS is to identify whether there exists a long-term relationship between EUA prices and its potential determinants. The existence of such a relationship allows drawing conclusions on the validity of economic theory with respect to its explanatory potential for EUA price dynamics. The single-equation relationships estimated in the previous chapter can only serve as a first check and for data selection. Therefore, we now carry out cointegration analyses in order to constitute any long-term relationships in the data. We then check whether these cointegration relationships are economically meaningful. Finally, we assess the impact of explanatory variables on the short-run dynamics of EUA prices in a vector error correction model (VECM) and a single-equation model.

Before discussing the results of our analyses, we would like to note that long-term relationships obviously need some time to develop. It is thus rather unlikely that such relationships were already established during Phase I of the ETS. Consistently, Rickels et al. (2007) and Hintermann (2010) found no cointegration during Phase I.[21] Creti et al. (2012) find a cointegration relationship for both Phase II and Phase I if a breakpoint is included for the price drop after the disclosure of significant overallocation in Phase I. While this seems surprising as the two other studies mentioned also accounted for this structural break, the conflicting results might be due to the application of different data and estimation procedures.[22] However, also Creti et al. (2012) show that the relationship in Phase I might not necessarily be economically meaningful: for example, there was no significant influence of the fuel switching price.

Following Creti et al. (2012) we include the EUA price (rolling future price), the oil price (brent oil, delivery in one month, negotiated at the ICE), the DJ Eurostoxx 50 Index and then test for various

---

[21] This is confirmed by Bredin and Muckley (2011) who also find cointegration during Phase II. Yet, their results need to be interpreted with caution because they implicitly include an electricity price series, which might might reverse the causal relationship and should only be considered at a more regionalized level (e.g., Bunn and Fezzi 2008; Fell 2010). Rather, Creti et al. (2012) serves as a good reference, because they restrict their analysis to input-related variables as the clean dark and spark spread “are influenced by the complexity of wholesale electricity pricing in specific European market platforms (p. 329)”.

[22] Whereas Creti et al. (2012) relies on the Johanson Trace Test (e.g., Johanson 1988), Rickels et al. (2007) for example uses the Barnejee Test (Barnejee et al. 1998) for a single error-correction model because they showed that the other prices are weakly exogenous.

combination of gas and coal prices as preselected in Section 3 in our cointegration analysis. We also include the various combination of these coal and gas prices as fuel switching prices. All price series are in logs and the optimal number is determined by the Akaike Info Criterion. Only in the specification where the fuel switching price from Point Carbon is used, we run the analysis in levels because this price series includes some negative entries. We apply two tests to identify whether a long-term stationary relationship exists among the I(1) variables: the Johanson Trace test and the Saikkonen and Lütkepohl test (e.g., Saikkonen and Lütkepohl 2000).[23] For completeness, we consider three cases: (i) the presence of only a constant, (ii) the presence of a trend which is assumed to be orthogonal to the error correction term, and (iii) the presence of a simple linear trend. Among the price series considered for the cointegration relationship, the EUA price, the oil price, and the DJ Eurostoxx 50 Index series are characterized by trends, whereas the gas and coal price series have no significant trend (except the one month ahead gas price with delivery to the National Balancing Point in the UK, which has a trend at the 10%significance level). The specification with a trend, which is orthogonal to the error correction term, seems to be the most reasonable one, as there are obvious trends among the variables. Table 8 shows the results of the cointegration tests.

Table 8: Cointegration test results for the I(1) variables and various combinations of gas and coal prices.

	Johansson Trace Test			Saikkonen and Lütkepohl Test		
	Constant	Constant and Orthogonal Trend	Constant and Trend	Constant	Constant and Orthogonal Trend	Constant and Trend
Gas and Coal Prices						
Coal ICE API2 Ro 1S[b]; Gas EEX Gaspool 1Y[c]	1*	1**	1**	0	0	1*
Coal ICE API2 ARA Index[d]; Gas EEX Gaspool 1Y[c]	0	1*	1*	0	0	1*
Coal ICE API2 Ro 1S; Gas ICE UK 1M[e]	2**	2**	2*	1**	2*	1***
Coal ICE API2 ARA Index[d]; Gas ICE UK 1M[e]	2**	2***	2**	2*	2**	2**
Fuel Switching Price						
Coal ICE API2 Ro 1S[b]; Gas EEX Gaspool 1Y[c]	0	0	0	0	0	0
Coal ICE API2 ARA Index[d]; EEX Gaspool 1Y[c]	0	0	0	0	0	0
Coal ICE API2 Ro 1S[b]; Gas ICE UK 1M[e]	0	1*	0	0	0	0
Coal ICE API2 ARA Index[d]; ICE UK 1M[e]	0	1*	0	0	0	0
Point Carbon Fuel Switching Price[a]	0	0	0	0	1*	0

[a]The test with fuel switching price from Point Carbon is based on a shorter time horizon as this price series is only available from the end of 2008 onwards. [b] Intercontinental Exchange Coal American Petroleum Institute Rotterdam 1-season ahead [c] European Energy Exchange Gaspool 1-year ahead future [d] ARGUS Coal American Petroleum Institute (API) 2 Cost Insurance and Freight (CIF) Amsterdam Rotterdam Antwerp (ARA) Daily Index Contract [e] Intercontinental Exchange Gas United Kingdom 1-month ahead future
Source: Own calculation

---

[23] For a detail description of the tests and procedure see Lütkepohl and Krätzig (2004) and the supplementary material for the Jmulti software (www.jmulti.de).

The results support once more the importance of the selected price series. While the price for gas delivered to the UK has up to two cointegration relationships, the price for gas delivered to Germany has at most one cointegration relationship.[24] At a 5% significance level, the test indicates that we need to account for at least one cointegration relationship when using gas delivered to UK.

Combing the gas and coal prices in order to directly test for the influence of fuel switching removes this cointegration relationship. These results remain unchanged if we use daily prices instead of average weekly prices. Consequently, we cannot confirm the result of Creti et al. (2012) who *do* find a cointegration relationship if they include the fuel switching price. In this regard, it remains to be discussed if structural breaks should be included in the test. On the one hand one could argue that the financial crisis induced a structural break in all markets—also commodities markets such as the ones for gas, coal, or EUAs. On the other hand, one could also argue that this effect is captured by the inclusion of variables representing economic activity (DJ Eurostoxx 50). Moreover, the EUA price series did not show a significant structural decrease in the direct aftermath of the Lehman bankruptcy, but mainly at the end of 2008. Including a break at the end of the year 2008 also results in a cointegration relationship when fuel switching prices are included.[25] In general, the inclusion of break points is questionable as one runs the risk of splitting the observations in small pieces, which allows identifying cointegration but simultaneously undermines the assumption of a stable long-term relationship. In the following, we do not consider breakpoints for Phase II.

We now investigate whether the existing long-term relationships are meaningful against the theoretical background outlined in Section 2. Consequently, we estimate the long-run relationships among the variables for gas price with delivery to the UK and for both coal prices (ARA and Rotterdam) because the Saikkonen-Lütkepohl test did not indicate cointegration for the other variables. For sake of completeness, we also estimate the long-run relationship when the fuel switching price is included, again only using the fuel price based on the gas price with delivery to the UK, as this is most likely case to have a cointegration relationship. We apply the dynamic ordinary least square (DOLS) method because the t-values obtained from standard OLS are upward biased and not reliable for identifying interference of the cointegration vector (Hamilton 1994).[26] Table 9 shows the results. We do not consider further exogenous variables in this step.

As expected, the estimation of the long-term relationships shows that there are almost no differences as to whether we use daily or weekly averaged data. Contrary to the single-equation regression in Section 3, coal prices (API2 ARA) have a significant influence. However, both the influence of coal and gas prices contradicts economic theory: an increase in the coal (gas) price is associated with an increase (decrease) in the EUA price. Combining them into the fuel switching price results in a small positive influence on the EUA price as it was found by Creti et al. (2012) in the long-term relationship, and as is predicted by theory. The oil price has a negative impact, which also contradicts economic theory if this price is considered as a proxy for economic activity. The influence of the DJ Eurostoxx Index 50 (economic activity) is positive as predicted.

---

[24] It should be noted that the price for gas delivered to Germany explained the largest fraction of variation in the auxiliary pretest regressions.

[25] These results are available upon request.

[26] We could also use FMOLS, but this does only lead to marginally different results which can be obtained from the authors upon request.

Table 9: Influence on EUA prices in long-term relationship

	DJ[a] Eurostoxx	Oil	Gas 1M UK[b]	Coal 1S RO[c]	Coal API2 ARA[d]	FS (UK-RO)[e]	FS(UK-ARA)[f]	Constant
daily	1.315***	-0.952***	-0.370***	1.382***	-	-	-	-5.936***
	1.293***	-0.803***	-0.373***	-	1.127***	-	-	-5.748***
	1.805***	-0.464***	-	-	-	0.103***	-	-9.956***
	1.812***	-0.470***	-	-	-	-	0.115***	-10.015***
weekly	1.317***	-0.992***	-0.443***	1.508***	-	-	-	-5.858***
	1.291***	-0.831***	-0.443***	-	1.219***	-	-	-5.621***
	1.882***	-0.468***	-	-	-	0.086*	-	-10.509***
	1.888***	-0.475***	-	-	-	-	0.098*	-10.551***

[a] Dow Jones [b] Gas 1 Month United Kingdom [c] Coal 1-season ahead Rotterdam [d] ARGUS Coal American Petroleum Institute (API) 2 Cost Insurance and Freight (CIF) Amsterdam Rotterdam Antwerp (ARA) Daily Index Contract [e] Fuel Switching Price (United Kingdom-Rotterdam) [f] Fuel Switching Price (United Kingdom- Amsterdam Rotterdam Antwerp)

Source: Own calculation

We complete our investigation by estimating the full model. Because there are no significant differences in the long-term relationship between the two coal prices, we use only the coal price with delivery to Rotterdam (one season ahead, negotiated at ICE) for this step. Since there was only limited evidence of a cointegration relationship with the fuel switching price, we estimate its impact on EUA prices in a single-equation framework (see below). Consequently, we estimate the Vector Error Correction model (VECM) only with the coal and gas prices (Table 10) on a daily basis.[27] For the estimation of the VECM, the Akaike Info Criterion and Final Prediction Criterion suggest to include up to two lags. We apply a two-stage procedure using the embedded subset model restriction search in JMulti based on the System Testing Procedure (Brüggemann and Lütkepohl 2001; Lütkepohl and Krätzig 2005).[28] This procedure sequentially eliminates the regressors with the smallest t-values until a certain threshold is reached. The procedure suggests that the coal price and the Eurostoxx 50 series can be considered as weakly exogenous and therefore do not restore to the equilibrium, implied by the insignificant error correction term. The restrictions are justified by the LR-test statistic which cannot reject the Null Hypothesis of using the restricted model against the alternative hypothesis of using the unrestricted model. Note that the LR statistic would even allow imposing further restrictions on the VECM. However, the LR statistic rejects the possibility to consider all variables except the EUA prices as weakly exogenous, which indicates that the market has developed since Phase I (for which Rickels et al. (2007) showed that this restriction is still valid). The results in Table 10 show that for all three variables (EUA, gas, and oil price) the error-correction term is significant. The negative sign implies reversion to the equilibrium.

---

[27] The VECM model based on weekly averaged data is available upon request from the authors.

Table 10: VECM Model

	DL EUA ICE RF0812[a]	DL Coal ICE Ro 1S[b]	DL Gas ICE UK 1M[c]	DL Eurostoxx 50[d]	DL Oil ICE Brent 1M[e]
EC (-1)	-0.016 [0.004] (-4.147)	-	-0.016 [0.005] (-3.168)	-	-0.010 [0.004] (-3.027)
DL EUA (-1)	0.087 [0.029] (2.946)	-	-	-	-
DL Coal (-1)	-0.124 [0.046] (-2.723)	0.110 [0.030] (3.718)	-	-0.101 [0.030] (3.389)	-
DL Gas (-1)	-	0.052 [0.015] (3.450)	0.052 [0.030] (1.768)	-	-
DL Eurostoxx (-1)	-0.094 [0.042] (-2.239)	0.049 [0.027] (1.822)	-	-0.101 [0.030] (-3.389)	-
DL Oil (-1)	-	0.038 [0.023] (1.681)	-	-	-0.099 [0.028] (-3.545)
DL EUA (-2)	-	-0.040 [0.018] (-2.255)	-	-	-
DL Coal (-2)	-0.100 [0.045] (-2.255)	-	-0.170 [0.057] (-2.973)	-	-0.105 [0.036] (-2.907)
DL Gas(-2)	-	-	-	-	
DL Eurostoxx (-2)	-0.075 [0.043] (-1.746)	-	-	-0.061 [0.028] (-2.171)	
DL Oil (-2)	-0.060 [0.034] (-1.752)	-	0.071 [0.043] (1.663)	-	
L Hydro France	0.002 [0.001] (2.838)	0.001 [0.001] (1.724)	-	-	-
L Hydro Sweden	-	-	0.002 [0.001] (1.739)	-	-
L Wind Denmark	-	-	-	-	-0.001 [0.001] (1.452)
L Wind Germany	-	-0.001 [0.001] (-1.719)	0.001 [0.001] (1.432)	-	0.001 [0.001] (-1.810)
L Wind Sweden	-	0.002 [0.001] (1.739)	-0.002 [0.001] (-1.810)	-	-
Trend	0.000 [0.000] (2.575)	-	0.000 [0.000] (1.810)	-	0.000 [0.000] (2.002)

[a] Log-Difference EUA Intercontinental Exchange Rolling Future [b] Log-Difference Coal Intercontinental Exchange Rolling Future 1-season ahead[c] Log-Difference Gas Intercontinental Exchange United Kingdom 1 month [d] Log-Difference Dow Jones Eurostoxx 50 [e] Log-Difference Oil Brent Intercontinental Exchange 1-month

Source: Own calculation

Having included the long-term relationship, it remains to look at the short-term dynamics. Here, the influence of lagged coal price variables is negative as expected by economic theory, even though it of course stands in contrast to the influence in the cointegration relationship. Yet, it is possible to properly interpret the influence of the other exogenous variables. As mentioned above, the influence of daily hydropower provision contradicts economic theory, implying that the EUA price increases (decreases) on days with high (low) hydropower provision. This could, again, be explained by regional interactions which cannot be observed at the aggregate level. One possible interpretation of this finding has to do with the fact that hydropower provision is influenced by weather variations through the resulting reservoir levels, i.e. the potential of hydropower provision. Actual hydropower provision is then determined by the decision of producers to which extent this potential is used. It might thus be the case that hydropower provision also indicates unforeseen demand peaks due to energy-demanding weather conditions across Europe. So, while France increases its hydropower production, other countries increase their coal-based electricity production, which is then reflected in higher EUA prices. In fact, hydropower provision in France is positively correlation with the coal price, and hydropower provision in Sweden is positively correlated with the gas price. Using reservoir level information and therefore information about the potential, instead of hydropower provision results in EUA price dynamics as theory predicts.

None of the exogenous variables for the provision of wind power shows any influence on the EUA price. Yet, they have an influence on the short-term dynamics of the gas and coal prices. Their influence is mixed, but might be explained with the different power system structure in the various countries, which deal in different ways with the intermittency issue of renewables energies. However, a further examination of these aspects is beyond the scope of this paper.

Finally, we return to the single-equation approach which seems to be appropriate for the fuel switching price because we could not find any cointegration relationships between the fuel switching price and the other variables. We use the specific-to-general approach as suggested by Herwartz (2010) to set up the model. Only the fuel switching price is included by assumption.

Table 11. Results of single-equation estimation

	Daily		Weekly	
	DL EUA[e]	DL EUA	DL EUA	DL EUA
DL FS (Gas UK Coal RO)[a]	0.0398**		0.0142	-
DL FS (Gas Gaspool Coal API2)[b]	-	0.1865**		0.1717*
DL Eurostoxx 50[c]	0.3598***	0.3354***	0.2859**	0.2141*
DL OIL (ICE Brent 1M)[d]	0.1286***	0.1001***	-	
L Wind Sweden	-0.0020**	0.0017**	-	
L Hydro France	0.0014**	0.0012*	-	
Resid Hydro Norway	-	-	-0.0500**	-0.0115**
R2	0.1108	0.1388	0.039	0.0803

[a] Log-Difference Fuel-switching price Gas United Kingdom Coal Rotterdam [b] Log-Difference Fuel-switching price Gaspool Coal American Petroleum Institute [c] Log-Difference Dow Jones Eurostoxx 50 [d] Log-Difference Oil Intercontinental Exchange Brent future price index 1Month [e] European Allowances

The results of the parsimonious model for daily and weekly data are shown in Table 11. They confirm our single-equation regression results in Section 3. Both specifications of the fuel switching price have a positive influence on the EUA price, even though the size of their influence is very different. The DJ Eurostoxx 50 index has a significant positive influence in every specification. Also the seasonally-adjusted residual series of hydro-reservoir filling in Norway has a robust negative influence, as one would expect. In contrast, hydropower provision in France has the “wrong” sign (from a theoretical point of view). A potential reason was discussed above.

5. Summary and Conclusion

The European Emission Trading Scheme (EU ETS) is the world’s largest market-based approach to internalize the external effects of pollution. It was established by the European Union in order to comply with the EU’s Kyoto targets in 2012. After an initial testing phase from 2005 to 2007 (Phase I), the ETS has now almost reached the end of its second phase (Phase II, 2008-2012), which, compared to the testing phase, was characterized by less volatility and jumps in allowance prices. Yet, we still observe a significant downward trend in prices towards the end of the phase. Even though the EU has already decided to continue using the ETS to control its greenhouse gas and carbon emissions in a Phase III (running until 2020), it remains important to understand price dynamics in the ETS, and assess whether the market provides a reliable price signal for carbon emissions and stipulates abatement in an efficient manner. In this paper we empirically investigate potential determinants of price dynamics. For this purpose we apply data covering almost the entire Phase II.

According to standard economic theory, the price of European Emission Allowances (EUAs) should reflect marginal abatement costs. In the EU ETS, where the majority of installations are based in the energy sector, fuel switching between gas and coal for electricity production is considered to be the most important short-term abatement option. As we demonstrate in a simple model, changes in gas and coal prices affect marginal abatement costs and should therefore help to explain EUA price dynamics. Additionally, fluctuations in energy demand (being mirrored in demand for allowances) should help to explain price dynamics. Yet, the marginal abatement approach could not explain price dynamics in Phase I of the EU ETS very well. The studies found rather mixed results and failed to explain the persistence of a positive price even after a substantial long position in the market was revealed. However, some studies using data from Phase II found evidence for a more mature market where a long-term stable relationship between EUA price and its determinants emerges. In particular, the fuel switching price has a significant influence.

In contrast to the existing studies, we put particular emphasis on the importance of price variable selection. In most empirical studies, only one price is chosen to represent e.g. the influence of coal price fluctuations. In reality however, there exists a large number of coal prices, e.g. at different maturities, trading places, and places of origin, and it is far from clear which price is relevant for fuel-switching decisions. Indeed, as pointed out by Schernikau (2010) and Zaklan et al. (2012), it is rather unlikely that one unique price will reflect the coal price across Europe. Running auxiliary single regressions to identify which price series explains variation in EUA prices best, we show that the various fuel price series have very different explanatory power for EUA prices. In fact, this might explain the mixed empirical results about the impact of fuel prices and fuel switching for Phase I because all authors chose different price series.

In our preliminary analysis, we find weak evidence for an impact of fuel switching on EUA prices, even though its explanatory contribution is rather limited. Moreover, as pointed out by Delarue et al. (2010) the relationship between the fuel prices and abatement is much more complex and cannot be observed by just looking at price series. They argue that fuel switching is evident—but only during some hours over the day. Once using daily aggregated data it might no longer be observed in the data. Moreover, our auxiliary regressions show a significant influence of economic activity as measured the Dow Jones Eurostoxx 50 Index and the oil price. Load values, which we use to capture the impact of weather conditions, do not have a significant influence on EUA prices. It seems that variations in load are either well planned by power utilities, or that the relevant variation in load values has been smoothed out by our aggregation. In general, the previous literature could only show a marginal influence of weather conditions.

The detailed analysis of renewable energy supply is a further innovation of our paper. We do not find strong evidence for the influence of renewables on EUA prices, either, except for the influence of reservoir levels in Norway. In the cases where the impact of renewables is statistically significant, it is in line with theory. In only one case, we find results opposing theory, i.e. hydropower in France being associated with an EUA price increase. Overall, it seems that the impact of renewables could better be investigated at the regional level rather than on the EU level.

Our analysis of cointegration relationships delivers mixed results. Cointegration analysis allows uncovering theoretically motivated long-term relationships in the data. We show that cointegration relationships exist, but that they depend strongly on the fuel price series used (e.g. gas prices for delivery to UK vs. delivery to Germany). Moreover, the relationships contradict theory as coal prices show a positive relationship with EUA prices, while gas prices show a negative relationship. Evidence for a long-run relationship between the fuel switching price and EUA price is very weak (in contrast to e.g. Creti et al. 2012).

In summary, only the influence of economic activity and hydropower provision in Norway is robustly explaining EUA price dynamics. Hence, it appears that also during Phase II the equalization of marginal abatement costs is not well supported by the data. The influence of fuel switching on EU price dynamics and therefore equalization of marginal abatement costs—in particular in the long run—is still rather small. In fact, this conclusion is supported by a survey carried out among German installations (Heindl and Löschel 2012). The survey revealed that abatement activities up to 2011 were mostly based on process optimization and in energy efficiency improvements whereas only 26 used fuel-switching for abatement purposes. However, as we already pointed out, the survey also reveals that only a minority of firms is involved in active trading, implying that abatement activities like fuel switching are not necessarily reflected in EUA prices.

Yet, our results could be interpreted to support the alternative option-value approach, in particular because studies based on the option-value approach also find a positive impact of the coal price, in case the possibility of cost-pass through is explicitly included (see Taschini and Urech 2010). Although the option-value approach still needs to be tested empirically for Phase II, we share the view of Hintermann (2012) that EUA price dynamics cannot be solely explained by the marginal abatement theory, but that also the option-value theory is needed to fully understand developments. Furthermore, we think that this explanatory approach could be improved by looking at the effects of thin trading and transaction costs (e.g. Montagnoli and de Vries 2010; Heindl, 2012). In turn, reducing transactions costs and uncertainty about overall emissions would reduce the option value in holding an EUA and therefore bring the market more back to equalization of marginal abatement costs.

Appendices

Table A.0 List of abbreviations of EUA Prices

BlueNext Spot	Spot price at BlueNext
EEX Carbix	European Energy Exchange Carbon Index
ICE Dec12	Intercontinental Exchange future prices with maturity at the end of Phase II
ICE Dec0812	Intercontinental Exchange rolling futures with maturity at the end of the year
NP Dec0812	Rolling futures with maturity at the end of the year
PC Dec12	Point carbon future prices with maturity at the end of Phase II
PC Dec0812	Point carbon rolling futures with maturity at the end of the year

List of abbreviations of coal prices

ICE API2 ARA	ARGUS Coal American Petroleum Institute (API) 2 Cost Insurance and Freight (CIF) Amsterdam Rotterdam Antwerp (ARA) Daily Index Contract
ICE API2 Ro 1M	Intercontinental Exchange Coal American Petroleum Institute Rotterdam 1-month ahead rolling future
ICE API2 Ro 1Q	Intercontinental Exchange Coal American Petroleum Institute Rotterdam 1-quarter ahead rolling future
ICE API2 Ro 1S	Intercontinental Exchange Coal American Petroleum Institute Rotterdam 1-season ahead rolling future
EEX API2 ARA 1M	European Energy Exchange Coal American Petroleum Institute Rotterdam 1-month ahead rolling future
EEX API2 ARA 1Q	European Energy Exchange Coal American Petroleum Institute Rotterdam 1-quarter ahead rolling future
EEX API2 ARA 1Y	European Energy Exchange Coal American Petroleum Institute Rotterdam 1-year ahead rolling future
EEX API4 RB 1M	Coal price FOB at Richards Bay 1-month ahead future
EEX API4 RB 1Q	Coal price FOB at Richards Bay 1-quarter ahead future
EEX API4 RB 1Y	Coal price FOB at Richards Bay 1-year ahead future
NYMEX 1M	New York Mercantile Exchange 1-month ahead future
MC NEW Price	McCloskey NWE Steam Coal Marker Price

List of abbreviations of gas pricesAPX ttf ind	APX-ENDEX Title Transfer Facility Index
EEX Gaspool 1Q	European Energy Exchange Gaspool 1-quarter ahead future
EEX Gaspool 1Y	European Energy Exchange Gaspool 1-year ahead future
EEX NCG_1Q	European Energy Exchange Gaspool 1-quarter ahead future
EEX NCG_1Y	European Energy Exchange Gaspool 1-year ahead future
ICE UK 1M	Intercontinental Exchange Gas United Kingdom 1-month ahead future
ICE UK 1Q	Intercontinental Exchange Gas United Kingdom 1-quarter ahead future
ICE UK 1S	Intercontinental Exchange Gas United Kingdom 1-season ahead future

Table A.1 Correlation between EUA prices from different sources in levels and in first differences

Correlation in levels

	BlueNext Spot	EEX Carbix	ICE Dec12	ICE Dec0812	NP Dec0812	PC Dec12	PC Dec0812
BlueNext Spot	1.000000	0.796818	0.954534	0.956657	0.955093	0.954469	0.956557
EEX Carbix	0.796818	1.000000	0.824754	0.831251	0.830601	0.824985	0.831374
ICE Dec12	0.954534	0.824754	1.000000	0.992357	0.991377	0.999826	0.992274
ICE Dec0812	0.956657	0.831251	0.992357	1.000000	0.997552	0.992291	0.999627
NP Dec0812	0.955093	0.830601	0.991377	0.997552	1.000000	0.991289	0.997566
PC Dec12	0.954469	0.824985	0.999826	0.992291	0.991289	1.000000	0.992552
PC Dec0812	0.956557	0.831374	0.992274	0.999627	0.997566	0.992552	1.000000

Correlation in first differences

	BlueNext Spot	EEX Carbix	ICE Dec12	ICE Dec0812	NP Dec0812	PC Dec12	PC Dec0812
BlueNext Spot	1	0.502792	0.973671	0.974229	0.882978	0.819023	0.826173
EEX Carbix	0.502792	1	0.478164	0.487544	0.490973	0.438557	0.451559
ICE Dec12	0.973671	0.478164	1	0.989573	0.899781	0.837630	0.836906
ICE Dec0812	0.974229	0.487544	0.989573	1	0.898262	0.828753	0.836527
NP Dec0812	0.882978	0.490973	0.899781	0.898262	1	0.759956	0.770467
PC Dec12	0.819023	0.438557	0.837630	0.828753	0.759956	1	0.988576
PC Dec0812	0.826173	0.451559	0.836906	0.836527	0.770467	0.988576	1

Source: Own calculation

Table A.2 Overview about various coal prices during Phase II

	2008					2009				
	Mean	StdDev	Coef.Var.	Min	Max	Mean	StdDev	Coef.Var.	Min	Max
ICE API2 ARA	13.47	2.92	0.22	7.43	19.30	6.83	0.67	0.10	5.90	8.98
ICE API2 Ro 1M	13.33	3.01	0.23	7.58	19.30	6.77	0.61	0.09	5.45	8.92
ICE API2 Ro 1Q	13.31	3.00	0.23	7.58	19.30	6.87	0.59	0.09	5.62	8.94
ICE API2 Ro 1S	13.24	2.87	0.22	7.89	19.17	7.27	0.56	0.08	5.83	9.19
EEX API2 ARA 1M	13.32	3.01	0.23	7.59	19.30	6.76	0.62	0.09	5.46	8.95
EEX API2 ARA 1Q	13.24	2.97	0.22	7.60	19.30	6.96	0.57	0.08	5.63	9.14
EEX API2 ARA 1Y	12.85	2.81	0.22	7.92	18.73	8.15	0.56	0.07	7.22	9.95
EEX API4 RB 1M	11.15	2.33	0.21	7.20	16.33	6.27	0.60	0.10	5.31	8.57
EEX API4 RB 1Q	11.09	2.34	0.21	7.17	16.41	6.43	0.49	0.08	5.46	8.49
EEX API4 RB 1Y	10.94	2.46	0.22	7.24	16.34	7.31	0.49	0.07	6.50	8.89
NYMEX 1M	8.59	1.75	0.20	5.18	12.34	4.78	0.66	0.14	4.00	6.76
MC NEW Price	13.60	3.01	0.22	7.48	19.01	6.85	0.64	0.09	5.75	8.85

	2010					2011					2012				
	Mean	StdDev	Coef.Var.	Min	Max	Mean	StdDev	Coef. Var.	Min	Max	Mean	StdDev	Coef. Var.	Min	Max
ICE API2 ARA	9.43	1.38	0.15	7.03	12.69	11.88	0.40	0.03	11.26	13.65	10.00	0.65	0.06	9.10	11.77
ICE API2 Ro 1M	9.44	1.40	0.15	7.07	13.44	11.81	0.38	0.03	11.13	13.36	10.09	0.60	0.06	9.13	11.73
ICE API2 Ro 1Q	9.45	1.33	0.14	7.15	13.13	11.84	0.39	0.03	11.18	13.42	10.27	0.56	0.05	9.30	11.74
ICE API2 Ro 1S	9.55	1.23	0.13	7.32	12.33	11.94	0.32	0.03	11.15	12.97	10.58	0.45	0.04	9.78	11.86
EEX API2 ARA 1M	9.44	1.39	0.15	7.00	13.29	11.81	0.39	0.03	10.99	13.45	10.09	0.61	0.06	9.13	11.74
EEX API2 ARA 1Q	9.49	1.3	0.14	7.08	12.78	11.84	0.37	0.03	10.95	13.01	10.37	0.57	0.05	9.25	11.78
EEX API2 ARA 1Y	10.17	0.81	0.08	8.65	12.37	12.07	0.32	0.03	11.28	12.91	11.37	0.58	0.05	10.26	12.50
EEX API4 RB 1M	9.42	1.06	0.11	7.70	13.06	11.47	0.45	0.04	10.71	13.72	10.11	0.61	0.06	9.03	11.28
EEX API4 RB 1Q	9.42	1.02	0.11	7.74	12.57	11.51	0.37	0.03	10.81	13.24	10.25	0.60	0.06	9.05	11.49
EEX API4 RB 1Y	9.80	0.79	0.08	8.41	12.02	11.69	0.31	0.03	10.93	12.49	11.02	0.51	0.05	10.07	11.98
NYMEX 1M	6.32	0.76	0.12	4.82	8.09	7.23	0.26	0.04	6.51	8.33	6.11	0.32	0.05	5.63	7.34
MC NEW Price	9.38	1.34	0.14	7.05	13.34	11.88	0.46	0.04	6.51	13.73	9.99	0.69	0.07	9.02	7.34

Table A.3 Overview about various gas prices during Phase II

	2008					2009				
	Mean	StdDev	Coef.Var.	Min	Max	Mean	StdDev	Coef.Var.	Min	Max
APX ttf ind	25.00	2.77	0.11	17.50	31.80	12.20	4.49	0.37	7.20	28.53
EEX Gaspool 1Q	28.92	6.18	0.21	18.57	39.76	13.52	2.10	0.16	10.58	19.45
EEX Gaspool 1Y	30.69	6.17	0.20	19.87	42.12	18.26	2.77	0.15	11.66	23.75
EEX NCG_1Q	29.54	6.23	0.21	19.00	40.89	13.80	2.20	0.16	10.61	19.88
EEX NCG_1Y	31.22	6.02	0.19	20.55	42.48	18.59	2.86	0.15	12.00	24.30
ICE UK 1M	26.61	3.69	0.14	20.65	36.90	12.18	3.83	0.31	7.08	24.31
ICE UK 1Q	28.76	5.97	0.21	20.99	40.86	13.58	4.54	0.33	10.48	24.59
ICE UK 1S	28.16	7.89	0.28	19.54	43.39	16.14	8.37	0.52	10.97	36.25

	2010					2011					2012				
	Mean	StdDev	Coef.Var.	Min	Max	Mean	StdDev	Coef.Var.	Min	Max	Mean	StdDev	Coef.Var.	Min	Max
APX ttf ind	17.41	3.41	0.20	10.7	25.23	22.70	1.28	0.06	17.07	25.71	22.22	0.19	0.01	21.01	22.51
EEX Gaspool 1Q	17.51	3.69	0.21	11.16	23.92	24.85	1.88	0.08	21.11	28.78	24.42	1.20	0.05	21.57	26.97
EEX Gaspool 1Y	19.62	2.30	0.12	14.93	24.33	26.23	1.34	0.05	22.73	28.20	26.63	0.78	0.03	25.20	28.20
EEX NCG_1Q	17.62	3.74	0.21	11.3	24.15	24.92	1.97	0.08	21.02	29.07	24.41	1.23	0.05	21.47	27.01
EEX NCG_1Y	19.74	2.28	0.12	15.03	24.44	26.29	1.34	0.05	22.76	28.26	26.65	0.80	0.03	25.25	28.25
ICE UK 1M	16.53	3.44	0.21	10.84	24.73	22.93	1.66	0.07	19.60	26.90	23.56	0.87	0.04	21.25	25.18
ICE UK 1Q	16.56	3.76	0.23	10.72	24.94	24.36	1.84	0.08	21.43	28.70	23.93	1.47	0.06	20.82	27.43
ICE UK 1S	15.09	3.50	0.23	10.77	20.46	24.64	2.73	0.11	19.79	29.68	26.00	2.78	0.11	20.93	30.62

Table A.4a Correlation of various coal price series in levels (coal prices measures in EUR/MWh)

	EEX API4 RB 1M	EEX API4 RB 1Q	EEX API4 RB 1Y	EEX API2 ARA 1M	EEX API2 ARA 1Q	EEX API2 ARA 1Y	ICE API2 ARA	ICE API2 RO 1M	ICE API2 RO 1Q	ICE API2 RO 1S	MC NEW Price	NYMEX 1M
EEX API4 RB 1M	1.000000	0.996586	0.964928	0.944533	0.946721	0.948103	0.936108	0.944035	0.945025	0.941566	0.926762	0.858947
EEX API4 RB 1Q	0.996586	1.000000	0.976247	0.940572	0.947469	0.954250	0.930515	0.940260	0.942713	0.943505	0.921492	0.856660
EEX API4 RB 1Y	0.964928	0.976247	1.000000	0.884472	0.900802	0.951417	0.871002	0.884188	0.892750	0.906645	0.863299	0.813284
EEX API2 ARA 1M	0.944533	0.940572	0.884472	1.000000	0.997405	0.964726	0.991930	0.999741	0.998188	0.991923	0.987653	0.910200
EEX API2 ARA 1Q	0.946721	0.947469	0.900802	0.997405	1.000000	0.975874	0.988461	0.997326	0.997804	0.995624	0.984045	0.914393
EEX API2 ARA 1Y	0.948103	0.954250	0.951417	0.964726	0.975874	1.000000	0.954177	0.964725	0.971227	0.980456	0.951246	0.898742
ICE API2 ARA	0.936108	0.930515	0.871002	0.991930	0.988461	0.954177	1.000000	0.992006	0.992815	0.983067	0.992419	0.910640
ICE API2 RO 1M	0.944035	0.940260	0.884188	0.999741	0.997326	0.964725	0.992006	1.000000	0.998470	0.992318	0.987608	0.910799
ICE API2 RO 1Q	0.945025	0.942713	0.892750	0.998188	0.997804	0.971227	0.992815	0.998470	1.000000	0.994766	0.988052	0.912023
ICE API2 RO 1S	0.941566	0.943505	0.906645	0.991923	0.995624	0.980456	0.983067	0.992318	0.994766	1.000000	0.979353	0.913371
MC NEW Price	0.926762	0.921492	0.863299	0.987653	0.984045	0.951246	0.992419	0.987608	0.988052	0.979353	1.000000	0.908976
NYMEX 1M	0.858947	0.856660	0.813284	0.910200	0.914393	0.898742	0.910640	0.910799	0.912023	0.913371	0.908976	1.000000

[a] ARGUS Coal American Petroleum Institute (API) 2 Cost Insurance and Freight (CIF) Amsterdam Rotterdam Antwerp (ARA) Daily Index Contract

[b] McCloskey NWE Steam Coal Marker Price

Table A.4b Correlation of various coal price series in log differences

	EEX API4 RB 1M	EEX API4 RB 1Q	EEX API4 RB 1Y	EEX API2 ARA 1M	EEX API2 ARA 1Q	EEX API2 ARA 1Y	ICE API2 ARA	ICE API2 RO 1M	ICE API2 RO 1Q	ICE API2 RO 1S	MC NEW Price	NYMEX 1M
EEX API4 RB 1M	1.000000	0.866096	0.797471	0.907071	0.825430	0.776004	0.434805	0.832830	0.768169	0.752032	0.127769	0.383599
EEX API4 RB 1Q	0.866096	1.000000	0.842885	0.831025	0.890759	0.800048	0.452973	0.795676	0.784647	0.764730	0.138118	0.405463
EEX API4 RB 1Y	0.797471	0.842885	1.000000	0.788003	0.816143	0.917028	0.435819	0.742201	0.734250	0.753424	0.158009	0.422080
EEX API2 ARA 1M	0.907071	0.831025	0.788003	1.000000	0.908137	0.826174	0.494740	0.902313	0.834966	0.804250	0.142161	0.400138
EEX API2 ARA 1Q	0.825430	0.890759	0.816143	0.908137	1.000000	0.870010	0.514206	0.851304	0.851957	0.816312	0.131317	0.406683
EEX API2 ARA 1Y	0.776004	0.800048	0.917028	0.826174	0.870010	1.000000	0.483063	0.789152	0.788280	0.800362	0.156366	0.431208
ICE API2 ARA	0.434805	0.452973	0.435819	0.494740	0.514206	0.483063	1.000000	0.539024	0.664965	0.510020	0.159202	0.282718
ICE API2 RO 1M	0.832830	0.795676	0.742201	0.902313	0.851304	0.789152	0.539024	1.000000	0.920319	0.870063	0.135427	0.429898
ICE API2 RO 1Q	0.768169	0.784647	0.734250	0.834966	0.851957	0.788280	0.664965	0.920319	1.000000	0.893448	0.143072	0.420961
ICE API2 RO 1S	0.752032	0.764730	0.753424	0.804250	0.816312	0.800362	0.510020	0.870063	0.893448	1.000000	0.151467	0.442996
MC NEW Price	0.127769	0.138118	0.158009	0.142161	0.131317	0.156366	0.159202	0.135427	0.143072	0.151467	1.000000	0.153195
NYMEX 1M	0.383599	0.405463	0.422080	0.400138	0.406683	0.431208	0.282718	0.429898	0.420961	0.442996	0.153195	1.000000

Table A.5 Correlation of various gas price series in levels and in first differences

Correlation in levels

	APX TTF IND	EEX GASPOOL 1Q	EEX GASPOOL 1Y	EEX NCG 1Q	EEX NCG 1Y	ICE UK 1M	ICE UK 1Q	ICE UK 1S
APX TTF IND	1	0.860525	0.802696	0.858298	0.803815	0.955882	0.886788	0.755392
EEX GASPOOL 1Q	0.860525	1	0.916823	0.998942	0.913816	0.914691	0.902698	0.707943
EEX GASPOOL 1Y	0.802696	0.916823	1	0.913052	0.999167	0.843576	0.803427	0.585696
EEX NCG 1Q	0.858298	0.998942	0.913052	1	0.911350	0.914767	0.907169	0.717232
EEX NCG 1Y	0.803815	0.913816	0.999167	0.911350	1	0.845450	0.806749	0.592502
ICE UK 1M	0.955882	0.914691	0.843576	0.914767	0.845450	1	0.936924	0.800147
ICE UK 1Q	0.886788	0.902698	0.803427	0.907169	0.806749	0.936924	1	0.866842
ICE UK 1S	0.755392	0.707943	0.585696	0.717232	0.592502	0.800147	0.866842	1

Correlation in log differences

	APX TTF IND	EEX GASPOOL 1Q	EEX GASPOOL 1Y	EEX NCG 1Q	EEX NCG 1Y	ICE UK 1M	ICE UK 1Q	ICE UK 1S
APX TTF IND	1	0.018233	0.012176	0.012803	0.005817	0.018838	0.031020	0.052140
EEX GASPOOL 1Q	0.018233	1	0.517124	0.957203	0.510776	0.477121	0.207791	0.069264
EEX GASPOOL 1Y	0.012176	0.517124	1	0.454386	0.976456	0.441659	0.208191	0.044901
EEX NCG 1Q	0.012803	0.957203	0.454386	1	0.464967	0.474531	0.206541	0.068331
EEX NCG 1Y	0.005817	0.510776	0.976456	0.464967	1	0.446526	0.210957	0.045481
ICE UK 1M	0.018838	0.477121	0.441659	0.474531	0.446526	1	0.236740	0.073209
ICE UK 1Q	0.031020	0.207791	0.208191	0.206541	0.210957	0.236740	1	0.694117
	0.052140	0.069264	0.044901	0.068331	0.045481	0.073209	0.694117	1

Table A.6 Correlation of various fuel switching price series in levels and in log differences

Correlation in levels

	PC AV	WR GASPOOL API2	FS WR UK API2	WR UK UK UT
PC AV	1	0.931018	0.923724	0.744430
WR GASPOOL API2	0.931018	1	0.995174	0.746947
WR GASPOOL UK	0.923724	0.995174	1	0.775700
FS WR UK API2	0.744430	0.746947	0.775700	1
WR UK UK UT	0.718423	0.722172	0.757561	0.997434

Correlation in log differences

PC AV	1	0.283474	0.286745	0.257216
WR GASPOOL API2	0.283474	1	0.975881	0.401623
WR GASPOOL UK	0.286745	0.975881	1	0.362159
FS WR UK API2	0.257216	0.401623	0.362159	1
WR UK UK UT	0.256633	0.366940	0.365402	0.981925

References

Acemoglu D, Aghion P, Bursztyn L, Hemous D (2012) The Environment and Directed Technical Change. American Economic Review 102(1):131–166

Alberola E, Chevallier J (2009) European carbon prices and banking restrictions: Evidence from Phase I (2005-2007). The Energy Journal 30(3):51–79

Alberola E, Chevallier J, Cheze B (2008) Price drivers and structural breaks in European carbon prices 2005–2007. Energy Policy 36:787–797

Allan A, Carroll R, Chen K, Garside B, Kruppa M, McGarrity J et al. (2012) Carbon Market Daily. Point Carbon. 9 (149)

Arthur WB (1989) Competing Technologies, Increasing Returns, and Lock-In by Historical Events. The Economic Journal 99(394):116-131

Barnerjee A, Dolado JJ, Mestre R (1998) Error-correction Mechanism Tests for Cointegration in a Single-equation Framework. Journal of Time Series Analysis 19:267-283

Beneking A (2010) Photovoltaik stellt die Systemfrage. Photon, H. 8:22–29

Benz E, Trück S (2009) Modeling the price dynamics of CO_2 emission allowances. Energy Economics 31:4–15

Bobinaitė V, Juozapavičienė A, Snieška V (2006) Correlation of Electricity Prices in European Wholesale Power Markets. Economics of Engineering Decisions 49(4):7–14

Boudoukh J, Richardson M, Shen Y, Whitelaw RF (2007) Do asset prices reflect fundamentals? Freshly sequeezed evidence from the OJ market. Journal of Financial Economics 83:397–412

Borak S, Härdle W, Trück S, Weron R (2006) Convenience yields for CO_2 emission allowance future contracts. SFB 649 Discussion Paper 2006-076. SFB Economic Risk, Berlin

Bredin D, Muckley C (2011) An emerging equilibrium in the EU emissions trading scheme. Energy Economics 33(2):353–362

Brüggemann R, Lütkepohl H. (2001) Lag selection in subset VAR model with an application to a U.S. monetary system, in Friedemann, R., Knüppel, L., Lütkepohl, H. (eds), Econometric Studies: A Festschrift in Honour of Joachim Frohn, LIT Verlag, Münster, 107-128

Bunn, DF, Fezzi C (2008) A vector error correction model of interaction among gas, electricity and carbon prices: an application to the cases of Germany and United Kingdom. Gullì, Francesco (Hg.): Markets for carbon and power pricing in Europe. Theoretical issues and empirical analyses. Cheltenham, UK , Northampton, MA, USA: Edward Elgar Publishing:145–159

Carmona R, Fehr M, Hinz J (2009) Optimal Stochastic Control and Carbon Price Formation. SIAM Journal on Control and Optimization 48(4):2168–2190

Chao H, Wilson, R (1993) Option value of emission allowances. Journal of Regulatory Economics 5(3):233–249

Chesney M, Taschini L (2012) The Endogenous Price Dynamics of Emission Allowances and an Application to Option Pricing. Applied Mathematical Finance, S. DOI:10.1080/1350486X.2011.639948

Chevallier J (2011) Detecting instability in the volatility of carbon prices. Energy Economics 33(1):99–110.

Chevallier J (2011) A model of carbon price interactions with macroeconomic and energy dynamics. Energy Economics 33(6):1295–1312

Christiansen AC, Arvanitakis A, Tangen K, Hasselknippe H (2005) Price determinants in the EU emission trading scheme. Climate Policy 5:15–30

Conrad C, Rittler D, Rotfuß W (2012) Modeling and explaining the dynamics of European Union Allowance prices at high-frequency. Energy Economics 34(1):316–326

Considine TJ (2000) The impacts of weather variations on energy demand and carbon emissions. Resource and Energy Economics 22:295–314

Convery F (2009) Origins and Development of the EU ETS. Environmental and Resource Economics 43(3):391–412

Convery F, Redmond L (2007). Market and Price Developments in the European Union Emissions Trading Scheme. Review of Environmental Economics and Policy 1(1):88-111

Creti A, Jouvet PA, Mignon V (2012) Carbon price drivers: Phase I versus Phase II equilibrium? Energy Economics 34(1):327–334

Daskalakis G, Markellos RN (2008) Are the European carbon markets efficient? Review of Futures Markets 17(2):103–128

Daskalakis G, Psychoyios D, Markellos R N (2009) Modeling CO_2 emission allowance prices and derivatives: Evidence from the European trading scheme. Journal of Banking and Finance 33(7):1230–1241

Ellerman D, Convery F, De Perthuis C (2010) *Pricing Carbon: The European Union Emissions Trading Scheme*. Cambridge University Press

European Environment Agency (EEA) (2011) Greenhouse gas emission trends and projections in Europe. Taking progress towards Kyoto and 2020 targets. EEA, Copenhagen 2011

European Union (EU) (2009) Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community. Official journal of the European Union 52(L 140):63-87.

EEX (2012) Index Beschreibung - Index description. Published by the European Energy Exchange AG. Leipzig

Feng Z, Zou L, Wei Y (2011) Carbon price volatility: Evidence from EU ETS. Applied Energy 88(3):590–598

Fell H (2010) EU-ETS and Nordic Electricity: a CVAR analysis. The Energy Journal 31(2):1–25

Hamilton JD (1994) Time Series Analysis. Princeton University Press

Heindl, P (2012) Transaction Costs and Tradable Permits: Empirical Evidence from the EU Emissions Trading Scheme. Centre for European Economic Research (ZEW). Mannheim. ZEW Discussion Paper, 12-021

Heindl P, Löschel A (2012) Designing Emissions Trading in Practice - General Considerations and Experiences from the EU Emissions Trading Scheme (EU ETS). Centre for European Economic Research (ZEW). Mannheim. ZEW Discussion Paper, 12-009

Herwartz H (2010) A note on model selection in (time series) regression models – general-to-specific or specific-to-general? Applied Economic Letters 17(12):1157–1160

Hintermann B (2010) Allowance price drivers in the first phase of the EU ETS. Journal of Environmental Economics and Management 59(1):43–56

Hintermann, B (2012) Pricing emission permits in the absence of abatement. Energy Economics 34:1329–1340

IEA (2009) World Energy Outlook 2009: International Energy Agency, Paris

Jäger-Waldau A (2012). PV Status Report 2011. European Commission, Joint Research Centre Institute for Energy, Renewable Energy Unit

Johansen S (1988) Statistical Analysis of Cointegration Vectors. Journal of Economic Dynamics & Control 12 (2/3), 231-254

Kalkuhl M, Edenhofer O, Lessmann K (2012) Learning or lock-in: Optimal technology policies to support mitigation. Resource and Energy Economics 34(1):1–23

Kanen JLM (2006) Carbon trading & pricing. London: Environmental Finance Publications

Kruger J, Pizer WA (2004) The EU Emission Trading Directive. Opportunities and Potential Pitfalls. Resources for the Future. Washington. Discussion Paper, RFF DP 04-24

Li R, Joyeux R, Ripple RD (2010) International Steam Coal Market Integration. Energy Journal 31:181–202

Linacre N, Kossoy A, Ambrosi P (2011) State and trends of the carbon market 2011. The World Bank. Washington D.C.

Lütkepohl, H, Krätzig, M (Ed.) (2004) Applied Time Series Econometrics. Cambridge University Press

Lütkepohl, H, Krätzig, M (2005) VECM Analysis in JMulti, http://www.jmulti.de/download/help/vecm.pdf

Mansanet-Bataller M, Pardo A, Valor E (2007) CO_2 Prices, energy, and weather. The Energy Journal 28(3):73–92

Mansanet-Bataller M, Chevallier J, Hervé-Mignucci M, Alberola E (2011) EUA and sCER phase II price drivers: Unveiling the reasons for the existence of the EUA–sCER spread. Energy Policy 39(3):1056–1069

Montagnoli A, Vries FPD (2010) Carbon trading thickness and efficiency. Energy Economics 32:1331–1336

Montgomery WD (1972) Markets in Licenses and Efficient Pollution Control Programs. Journal of Economic Theory 5:395–418

Oberndorfer U (2009) EU Emission Allowances and the stock market: Evidence from the electricity industry. Ecological Economics 68(4):1116–1126

Paolella MS, Taschini L(2008) An Econometric Analysis of Emission Allowances Prices. Journal of Banking and Finance 32(10):2022–2032

Rickels W, Duscha V, Keller A, Peterson S (2007) The determinants of allowance prices in the European Emissions Trading Scheme - Can we expect an efficient allowance market 2008? Kiel Institute for the World Economy. Kiel. Kiel Working Papers, 1387

Roberts MJ, Spence M (1976) Effluent Charges and Licenses Under Uncertainty. Journal of Public Economics 5:193–208

Schennach SM (2000) The Economics of Pollution Permit Banking in the Context of Title IV of the 1990 Clean Air Act Amendments. Journal of Environmental Economics and Management 40(3):189–210

Schernikau L (2010) The Renaissance of Steam Coal. Economics of International Coal Trade. Berlin: Technical University of Berlin

Saikkonen P, Lütkepohl H (2000) Testing for the Cointegrating Rank of a VAR Process with Structural Shifts. Journal of Business & Economic Statistics 18 (4):451-64

Schiffer H (2005) Energiemarkt Deutschland. 9. Aufl.: T Ü V Verlag GmbH, Köln

Schmalensee R (2012) Evaluating policies to increase electricity generation from renewable energy. Review of Environmental Economics and Policy 6:45–64

Seifert J, Uhrig-Homburg M, Wagner M (2008) Dynamic behavior of CO2 spot prices. Journal of Environmental Economics and Management 56(2):180–194

Sijm JPM., Bakker SJA, Harmsen HW, Lise W, Chen Y (2005) CO_2 price dynamics. The implications of EU emission trading for the price of electricity. Energy research Centre of the Netherlands. ECN-C-05-081

Stephan N (2012) Tendances Carbone. The Monthly Bulletin on the European Carbon Market. Herausgegeben von CDC Climate Research. 71

Taschini L, Urech S (2010) The real option to fuel switch in the presence of expected windfall profits under the EU Emission Trading Scheme. The Journal of Energy Markets 3:27–47

Tendances Carbone (2007) Methodological Notes

Tendances Carbone (2012) A newsletter of CDC Climate research in partnership with Bluenext and metnext. No 71, July 2012

Tietenberg TH (1985) Emissions trading. An exercice in reforming pollution policy. Washington, D.C: Resources for the future

Warrel L (2006) Market Integration in the International Coal Industry: a cointegration approach. Energy Journal 27:99–118

Wilkes J, Moccia J (2010). Wind in Power 2009 European Statistics. The European Wind Energy Association (EWEA)

Zaklan A, Cullmann A, Neumann A, von Hirschhausen C (2012) The globalization of steam coal markets and the role of logistics: An empirical analysis. Energy Economics 34(1):105–116

Zhang Y, Wei Y (2010) An overview of current research on EU ETS: Evidence from its operating mechanism and economic effect. Applied Energy 87(6):1804–1814