# The EU ETS 3rd Trading Period and Price Formation

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**Abstract**

Since its introduction, the European Emissions Trading System (EU ETS) has undergone a series of changes in the market design and experienced constant political debates about future adjustments. Particularly, substantially changes have been introduced between the second and the current third trading period. In this paper we analyze whether these changes have effectively fostered market functioning by analyzing the price formation of European Emission Allowances (EUA). We find a strong structural break in price formation around the end of the second trading period. After the break we find a much stronger connection between short term CO2 abatement related variables such as coal and gas prices and EUA prices in the third EU ETS trading period compared to the second trading period. We interpret these findings as evidence for a positive economic effect of the improved market design in the third trading period. Moreover, we find an increasing volatility of EUA returns during the first months of the third trading period. This finding highlights the fact that market reforms did not only improve the functioning of the market, but came at the price of uncertainty among market participants and higher price volatility. Finally, we assess the role of political events for EUA price formation using a GARCH model. Accounting for conditional variance in this way reduces the number of significant policy events considerably compared to other studies on the matter which do not explicitly account for conditional heteroskedasticity.

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JEL classification:

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## 1. Introduction

Political decision makers face great challenges when designing and especially re-designing markets for pollution control. On the one hand, there might be situations when it is economically reasonable and efficient to change market design - for instance, because of misuse of market rules by individual agents, unintended spill-overs to adjacent markets or to align market outcomes with political targets. On the other hand, a change in market rules or even just their announcement may induce severe uncertainty into the market. While appropriate communication strategies have been intensively discussed in Central Bank policy, it is largely neglected in research on market re-design for pollution control such as cap-and-trade.

In this paper, we analyze how political interventions have influenced efficiency and uncertainty of the world's largest cap-and-trade system, the *European Emissions Trading Scheme for CO2 emission allowances* (EU ETS). The EU ETS was introduced in 2005 to attribute a price to carbon emissions and to provide financial incentives for reducing these emissions. The market outcome in a cap-and-trade system can be considered being efficient if the allowance price reflects actual marginal abatement cost. However, previous analyses have identified different and severe price distortions and inefficiencies of the emissions certificates (Hintermann (2010); Hintermann et al. (2016)). Therefore, European policy has initiated several adjustments to the trading regime over time to increase market efficiency. Especially in and between the phases 2 and 3, regulation has changed substantially. In the third trading period the majority of certificates are auctioned to market participants instead of free allocation of allowances that was the predominant allocation mechanism during the second trading period. Furthermore, a single cap for the entire EU has been introduced and banking of allowances has been permitted. Since the beginning of current third phase two further refinements were established. The instruments backloading and market stability reserve (MSR) were introduced as tools to temporarily withhold certificates from auctioning when certificates are not scarce and allowance caps have been tightened.

The aim of this paper is to analyze whether these market interventions have improved the functioning of the market. A market for emission allowances can be considered well-functioning if the allowance price is closely tied to movements in variables representing actual marginal abatement cost. Hence, we model prices of European Emission Allowances (EUA) as a function of theoretically motivated fundamental drivers of abatement costs. The political reforms can be considered successful if the explanatory power of market fundamentals on allowance prices improves. On the other hand, political reforms may have unintended effects conflicting a better functioning of the EUA market. For example, a modification of the market design and its communication to the market may increase regulatory uncertainty (Koch et al. (2014)). An increasing uncertainty of future EUA prices increases uncertainty regarding a firm's optimal abatement strategy. Consequently, fundamentals lose their explanatory power with respect to prices during periods of increased uncertainty. We therefore analyze market uncertainty in terms of EUA price volatility corresponding to the announcement and launch of market reforms. If price volatility increases after (the announcement of) a market reform (such as the introduction of the third trading period), then market uncertainty has increased and the reform may have a contrary effect. To account for potential changes in market uncertainly we allow for time varying volatility using a generalized autoregressive conditional heteroskedasticity (GARCH) framework and test for structural breaks in the relationship between the EUA price and its fundamental drivers. Moreover, GARCH based volatility forecasts allow us to obtain an estimate for uncertainty and, hence, allows us to assess whether uncertainty increased after (the announcement of) reforms.

Previous literature on the economic role of regulatory uncertainty in pollution control markets is limited, assessment of the recent third phase of the EU ETS is scarce. Noteworthy examples are Hitzemann et al. (2015) and Koch et al. (2016). Hitzemann et al. (2015) show from a finance perspective that regulatory announcements about realized emissions – which can be seen as an indicator of future strictness of the cap – lead to significant abnormal returns on the event day, accompanied by high intraday volatility. Koch et al. (2016) analyse the linkage between political announcements and market outcome in an event study setup, finding that market participants are highly responsive to political events. Overall, both papers do not address structural change andor time varying volatility explicitly and are therefore not able to identify the effects of market reforms and the corresponding announcements.

The remainder of this paper is organized as follows. Section 2 describes the institutional background. Section 3 introduces the theoretical framework and explains the selection of variables. In Section 4, we present the results of our econometric analysis. Section 5 concludes.

## 2. The EU-ETS: Institutional Background

The European Union's Emissions Trading Scheme traces back to December 1997, when the Kyoto Protocol had been signed. The EU member states at that time declared to reduce greenhouse gas emissions by 8 percent compared to 1990 emissions levels until 2012 (United Nations (1998), (United Nations (2014)). The main instrument of the European climate policy became a market based cap and trade mechanism, the EU ETS. Emitters of carbon dioxide working in industries covered by the EU ETS must surrender one emission certificate at the end of a compliance or trading period for each ton of CO2 emitted. These certificates are freely allocated or auctioned out on the primary market and traded on the secondary market. During the first phase almost all allowances were freely allocated. In the second trading period 90 percent were allocated for free. From 2013 onwards, large auctioning has become the dominant feature of the EU-ETS, and 57 percent of the total amount of allowances in the third phase shall be auctioned.

Auctions or the primary market is the EC's default method of allocating emission allowances within the EU-ETS (European Commission (2016c)). The auctions are organized via private platforms, the European Energy Exchange (EEX) in Leipzig acting for the majority of participating countries and the Inter-Continental Exchange Futures Europe (ICE) in London. At least 50 percent of the revenues of the auctions are meant to be used for climate and energy related purposes. The secondary market is organized as an exchange between companies (over the counter, OTC) or on a private trading platform with standardized products. The most important platforms are again the EEX and the ICE. Both offer a full forward curve including monthly and quarterly futures and a daily spot market. Despite the variety of products, the EUA December Future contract as traded on the ICE ECX Platform is the most - and only - liquid future on the platform (Creti et al. (2012); Koch et al. (2014)). On the other hand, overall trading has developed strongly since 2005 (European Commission (2016a)). In the first phase trading volumes increased from 321 million allowances in 2005 to 1.1 billion in 2006 and 2.1 billion in 2007. In the second period, trading volumes developed from 3.1 billion in 2008 and 6.3 billion in 2009 to 7.9 billion allowances in 2012, with a market value of EUR 56 billion (European Commission (2016a)). In 2014 and 2015, total trading volume in EU ETS has declined for the first time in its history compared to 2013 (European Enery Exchange (2016)). However, data for 2016 indicates an increase in trade again. A prerequisite for participation in the secondary market is a registration in the EU ETS Union Registry. The registry records information on the number of CO2 allowances, the movement of allowances (allocations, transfers and surrenders), the annual verified emissions and the compliance status (Department of Business, Energy and Industrial Strategy (2016)). Since June 2012, a single registry system is operated and managed by the European Commission. The Member States have a national administrator and a national registry section within the single Union Registry.

The first trading period started in 2005 and lasted until 2007. It is considered as the pilot phase of the EU ETS (European Commission (2016a)). An annual emissions cap was defined by every member state by so called National Allocation Plans (NAP). These NAP were sent to the EC for approval. EU member states were obliged to allocate at least 95 percent of the allowances for free. In its first phase, the EU ETS covered the sectors electricity generation and energy intensive industries (like iron and steel, refineries, cement, glass and pulp and paper) only. Companies had to surrender allowances for any ton of CO2 they emitted. In case of non-compliance, fines were set at 40 EUR. The generous allocation and the very loose emissions cap led to an over-allocation of millions of allowances. In other words, overall emissions were far below the allowed quantities. In spring 2006, the market acknowledged this after real emissions of the year 2005 had been published. As a result, EUA prices collapsed from around 30 EUR to 9 EUR. As banking was not allowed in the first phase, EUA prices melted close to zero at the end of 2007. Overall, the first phase cannot be interpreted as successful. Hintermann (2010) for instance has shown that during the first phase emissions certificate prices were not driven by variables representing marginal abatement costs. This casts doubt on the efficiency of the EU ETS which in theory requires the equality of marginal abatement cost and the EUA prices. The most important achievement of this phase was that market participants had time to gather experience with using free EUA trade on the secondary market. Further market participants learned the regulatory requirements of measuring and verifying emissions data. Finally, the developments during the first phase and regulatory experiences provided a basis for improving market rules and to set national EUA quantities for the second phase of the EU ETS.

The second trading period runs from 2008 through 2012, where a European emissions cap was set with a 6.5 percent emissions reduction compared to 2005 levels. The NAP had to be adapted consequently. Three additional countries joined the EU ETS, namely Liechtenstein, Iceland and Norway, and so did the new EU member states Bulgaria and Romania. The industry base was extended by especially energy intensive elements of the chemical industry. Also, nitrous oxide emissions were included by a number of countries (European Commission (2016a)). Auctioning took a larger role, the proportion of free allocation decreased to 90 percent. The penalty for non-compliance was increased from 40 to 100 EUR. Based on Directive 2008/101/EC the aviation sector has been included from 2012 onwards. Initially, flights to, from and within the European Union were meant to be included, criticism by several foreign countries as China and the US led to a suspension of any flight originating or destinating outside of the EU until 2016 (European Commission (2016d)).

The most important development, however, was that market participants drastically increased their use of two additional climate policy instruments covered by the Kyoto protocol, namely the Clean Development Mechanism (CDM) and Joint Implementation (JI) Projects. CDM projects are so called green investments in developing countries which either reduce local CO2 emissions or absorb carbon dioxide (i.e. reforestation). Investors in CDM projects receive tradeable Certified Emission Reductions (CERs) which are convertible into EUA. Comparable to that, investors can obtain Emission Reduction Units (ERU) when they invest in emissions reductions in transition countries. As both CERs and ERUs were convertible to EUAs, they can be understood as additional allowance supply. Firms were allowed to buy these international certificates for up to 1.4 billion tons of CO2 equivalent (European Commission (2016a)) and use them for compliance in the EU ETS.

EUA prices fell under the massive influence of the global financial crisis during the the first two years of the second phase. European GDP, output from energy intensive sectors and, by that, demand for EUA decline dramatically while the NAP and the issued quantities were not adapted (European Commission (2016a)). While in the second half of 2008 the average price was around EUR 22 per ton CO2, it was nearly halved to EUR 13 in the first two quarters of 2009 (Parliament Committee on Climate Change (2009)). A market reaction on regulatory announcement in a broader sense occurred in December 2009, when after the Copenhagen climate change conference prices dropped further to figures around EUR 12. The cumulated oversupply of permits became formative for the market in the second half of 2012, when allowance prices were constantly below EUR 10 per ton CO2. At the end of phase 2, a surplus of 1.5 billion allowances let the price drop further even below EUR 5.

The current third phase of the EU ETS has started in 2013, lasting until 2020. It is based on the EC's 2020 climate and energy package, targeting at a GHG emissions reduction of 20 percent compared to levels in 1990, a renewable energy sources share of 20 percent in energy production and a 20 percent increase of energy efficiency (European Commission (2016e)). For the third period, the EU ETS has been extended to additional industries, namely the (entire) chemical industry, non-ferrous metals and the gypsum industry. As of 2013, the EU ETS covers 50 percent of the European CO2 emissions of the participating states. In comparison to the first two phases, additional regulatory adjustments have been adopted. The most prominent change is probably the change from free allowance allocation to an auction system. Starting with 40 percent in 2013, emission allowances are going to be auctioned off for most of the industries covered by the ETS. Article 10 (1) of the EU ETS Directive defines that 88 percent of the total auction volume shall be allocated to the

Member States in accordance with their emissions; 10 percent shall be distributed to the poorest EU Member States and 2 percent according to Kyoto protocol achievements. The generated funds are meant to be spent mainly on climate and energy related purposes such as energy efficiency, renewables, research and sustainable transport.

Notable exemptions from the auction rule are the manufacturing and the aviation sector in order to avoid carbon leakage. The manufacturing sector received 80 percent of allowances for free in 2013, with a planned steady decline to 30 percent in 2030. As defined in Art. 10a of the ETS Directive, a sector is exposed to a significant risk of carbon leakage if direct and indirect costs induced by the implementation of the directive would increase production cost by at least 5 percent; and the sector's trade intensity with non-EU countries (imports and exports) is above 10 percent. The aviation industry have received 85 percent of the allowances for free within the third trading period. To give incentives for climate friendly carriers, allowances are distributed according to a benchmark. Companies meeting this benchmark receive between 80 percent and 100 percent for free. Less efficient companies receive only a share of their expected emissions as free certificates.

The next important change was the replacement of NAP by a true single European emissions cap – individual national caps became obsolete – with a linear annual reduction factor of 1.74 percent. A third innovation of the market design has been the introduction of the so-called banking of allowances, which describes the option of saving allowances for a future compliance period. These changes were intended to increase the functioning of the EU ETS, decrease allowance surplus and, by that, to stabilize previously low market prices. The latter aim, however, was not reached. Within the first year, allowance surplus increased by 100 million. The European Commission identified two main drivers of this development. The first was the ongoing effects of the economic crisis from 2009, the second was intensive use of the CDM in the late phase two, creating high numbers of CER (European Commission (2016b)). Although the European Commission restricted their use in phase three, the allowance surplus remained high, with low corresponding allowance prices. To secure long term investment signals from the EU ETS, the European Commission decided to cut the surplus by introducing a policy called Backloading in early 2014. In the 2014 auction, 400 million allowances had been taken out of the overall auctioned quantity with additional 300 million in the 2015 and another 200 million in the 2016 auction aiming at a stabilization of allowance supply and demand in the short run (European Commission (2016b)). The allowances backloaded are meant to be auctioned in 2019-2020. As a second pillar of their stabilization policy, the European Commission proposed the introduction of a Market Stability Reserve (MSR), which shall put into force in January 2019 and shall work as follows: whenever the allowance surplus exceeds 833 million certificates, the annual auction quantity shall be reduced by 12 percent. If, on the other hand, the expected surplus falls below 400 million certificates or if prices jump strongly, the auction quantity shall be increased by 100 million certificates. Allowance reduction and increase will be organized via the Market Stability Reserve. Also, the backloaded allowances shall be transferred into the MSR.

In the following sections, we are going to analyse whether the market interventions in Phase 3 have been successful in improving the functioning of the market, that is, whether abatement costs are better reflected in the EUA market price than in the previous phase.

## 3. Theoretical Motivation and Variable Selection

The EUA market has experienced considerable design changes in the recent past while even more changes may still lie ahead. In this paper, we analyze the impact of political interventions on the development of price dynamics and market risk/uncertainty. Montgomery (1972) has shown that under perfect market conditions abatement costs are equal to the permits price in equilibrium. Rational agents optimally trade allowances or abate until the market price meets their individual marginal costs of abatement. In a dynamic set-up, the marginal cost of abatement depend on the future expectations of market fundamentals Hintermann (2010). Marginal abatement curves for any firm can be modeled as a function of a firm's expectation on expected own emissions and cost factors reflecting individual abatement. In an extensive review, Hintermann et al. (2016) have identified a variety of price fundamentals affecting allowance demand (i.e. marginal cost of abatement) such as prices for gas and coal, fossil electricity substitutes from renewable generation and macroeconomic factors like economic growth or the energy and carbon intensity of an economy.

The aim of this paper is to identify whether market interventions have improved the functioning of the market. A market for emission allowances can be considered well-functioning if the allowance price reflects actual marginal abatement cost. Therefore, we model EUA prices as a function of theoretically motivated fundamental drivers of these costs. Adjustments of the market design are considered to be successful if allowance prices can be better explained by market fundamentals after the intervention. Accordingly, actual abatement costs are better reflected in the market price. Hence, to assess the efficiency of changes in the market design we empirically test whether after the policy intervention the market fundamentals have a stronger effect on EUA prices.

On the other hand, political interventions may have unintended effects contradicting a better functioning of the EUA market. In particular they can lead to increased uncertainty about future regulatory changes (Koch et al. (2014)) and uncertainty about the market environment while agents adapt to the new market design. An increasing uncertainty of future EUA prices increases uncertainty regarding a firm's optimal abatement strategy. As a consequence, marginal abatement costs might be less responsive to the fundamental drivers. Accordingly, we analyze the development of market uncertainty in terms of EUA price volatility in relation to political reforms and announcements to identify potential drawbacks concerning market functioning. We argue that if price volatility increases after an announcement of a reform beyond the volatility induced from market fundamentals, then market uncertainty has increased. This, however, would lead to an increase of the absolute cost of hedging against price risks for any risk averse agent.

As dependent variable, we employ the relative price change (return) of EUA Dec Future contract as traded on the ICE ECX platform. Following Creti et al. (2012) and Koch (2014) we identified the Dec Future as the most – and only – liquid future contract on the platform. A first set of covariates links the EUA return with relative price changes of fossil fuels. Electricity generation accounts for 60 percent of the CO2 emissions in the EU-ETS. More than 75 percent of emissions from electricity generation stem from coal fired power plants. A fuel switch can be considered the most relevant abatement option in the short run Hintermann et al. (2016). Therefore, we use European coal price changes as first market fundamental to explain allowances prices. Following Koch et al. (2014) and Koch (2014) the coal price is represented by the ICE month ahead future which is based on the Argus McCloskey's API2 CIF ARA index. We expect EUA prices to decrease with an increase of coal prices, as increasing coal prices reduce electricity generation from coal in favor of less CO2 intensive power plants.

As a second fuel price, we employ daily year-ahead natural gas futures as traded on the Dutch Tile Transfer Facility (TTF).[1] This market place is considered to be the most liquid hub in continental Europe and the benchmark for other continental European hubs (Heather (2012)). As a natural gas fired power plant emits some 50 percent of CO2 per MWh compared to a coal plant, we expect the opposite relation of natural gas and allowance prices and the EUA price to increase when gas prices increase.

Electricity generation from fossil fuels is also related to electricity generation from renew-

[1] Alternatively, we may use one month-ahead gas futures. There was however virtually no difference in the results.

able electricity sources. To account for renewable electricity generation, we introduce three variables. The first two are European feed-in renewable energy sources in MWh. We take into account daily electricity generation from wind sources in Germany, Denmark, Sweden and the UK as well as daily solar power generation in Germany and Sweden. The supply of renewable electricity generation crowds out fossil fuel generation. Therefore, the demand for allowances from fossil fuel generation is decreased, leading to lower EUA prices. Our third variable related to renewables are Nordic hydro reservoir levels which serve as a proxy for expected hydro generation. Particularly, we are considering hydro storage fillings in Norway and Finland. Following Hintermann (2010) and Rickels et al. (2015) we assume that reservoir levels influence the future availability of renewable energy and, by that, the demand for allowances. A positive change of reservoir levels can be expected to lead to decreasing allowances prices.

A next type of explanatory variables relates EUA prices to macroeconomic developments. Since CO2 allowance demand is assumed to increase with short term economic growth, we include different economic development and sentiment indicators. Following Koch et al. (2014), we include the Stoxx Europe 600, which incorporates the stocks of large, mid and small capitalization companies from 18 European countries (Stoxx Limited, 2015a). In order to control for current expectations about the stance of the business cycle, we include the Economic Sentiment Indicator (ESI) which is based upon business surveys in all EU member states. As alternative measure for economic development, following various studies (Creti et al. (2012), Bredin and Muckley (2011) or Chevallier (2009)), we also include the Euro Stoxx 50 stock index which is Eurozone's leading blue-chip index covering 50 stocks from 12 Eurozone countries. Additionally, following Rickels et al. (2015), we take into account the Euro Stoxx Oil and Gas Index as well as the Euro Stoxx Utilities Index which measure economic activity in the oil gas and electricity sector, respectively. Lastly, the impact of the sub-indices Euro Stoxx Total Market Foresty and Paper and Euro Stoxx Basic Materials and Resources is evaluated. As another proxy for macroeconomic development the spread of the yield curve as issued by the ECB is considered. This yield spread between 10-year and 3-month maturity government bonds incorporates government bonds of all issuers within the Euro Area with a triple A rating. A factor that may also affect EUA prices is the price of CERs (Certified Emission Reductions) as CERs can be seen as a perfect substitute for EUAs. Specifically, we are considering the settlement price of the CER Mid Dec Continuous price series as traded on the EEX.

To identify the effect of political interventions, either directly as policy event or expected as an announcement, we follow Koch et al. (2014) and Koch et al. (2016) and include several event dummies. We distinguish between announcements concerning (1) market design and long term policy. Here, we expect a positive impact on market functioning. A next series of events can be attributed to (2) backloading decisions. Closely related but not similar are announcements regarding (3) the Market Stability Reserve (MSR) . For both (2) and (3) we expect an increase in volatility, indicating a higher risk for market agents. The fourth category (4), while not related to policy events, captures non-fundamental price movements brought about by the behavior of market participants around the annually re-occurring submission date at which installations need to submit the required quantity of allowances for the previous year. A last category is (5) other events. Using event dummies, we try to capture the impact of (changes in expectations about) market design changes and future supply of certificates on the EUA price.

# 4. Econometric Analysis

## 4.1. Descriptive Statistics

In order to study whether changes of the market design during the third EU ETS trading period had an impact on EUA price formation, we start by examining the development of EUA prices presented in Figure 1. While the second trading period (2008 – 2012) is characterized by higher EUA prices and large price drops, the variation during the third trading period (2013 – 2016) seems less extreme in absolute values. Inspecting EUA price returns defined as the log-differences of the EUA prices we observe episodes of high volatility during the first months of the third trading period (see Figure 2). This finding becomes even evident when estimating a GARCH(1,1) model for the (mean-adjusted) EUA returns. Figure 3 presents the one-month ahead forecasts of the conditional standard deviation, which confirms the high volatility regime during the first six months of the third trading period. Given the prominent time variation in the volatility of EUA returns supports the presence of volatility clusters, a feature that was only occasionally accounted for in existing empirical studies (see e.g. Conrad et al. (2012) or Boersen and Scholtens (2014)).

The EUA price is determined by supply and demand of certificates. The overall EUA supply is determined by the policy maker. However, supply and demand in the secondary market where EUA are freely traded is determined by the CO2 abatement cost of the market participants. These abatement cost depend on a set of variables which are labelled as "fundamental drivers" of CO2 prices. There is a large number of variables in the literature that are regarded as potential fundamental drivers of EUA prices. As explained above in


Figure 1: Price of EUA December Futures (€ per ton of $CO_2$) for the 2nd (2008-2012) and 3rd (since 2013) trading period

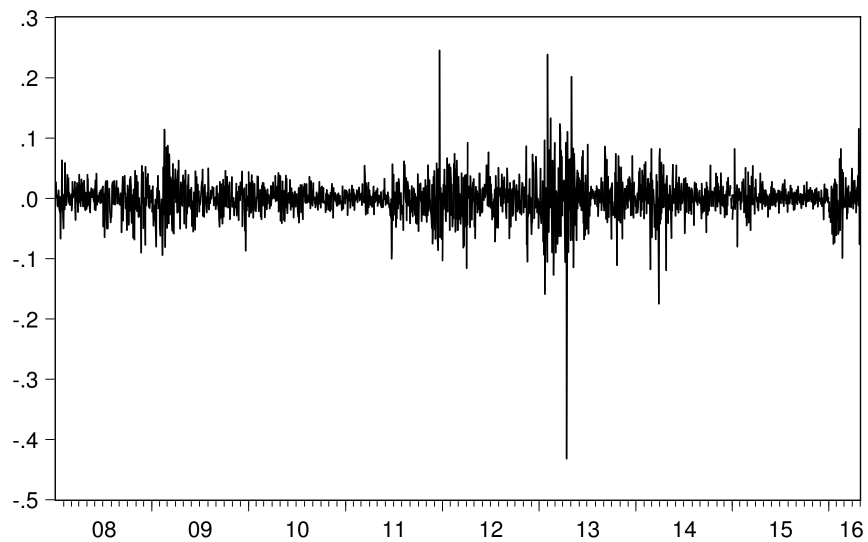


Figure 2: Returns of EUA December Futures for the 2nd (2008-2012) and 3rd (since 2013) trading period

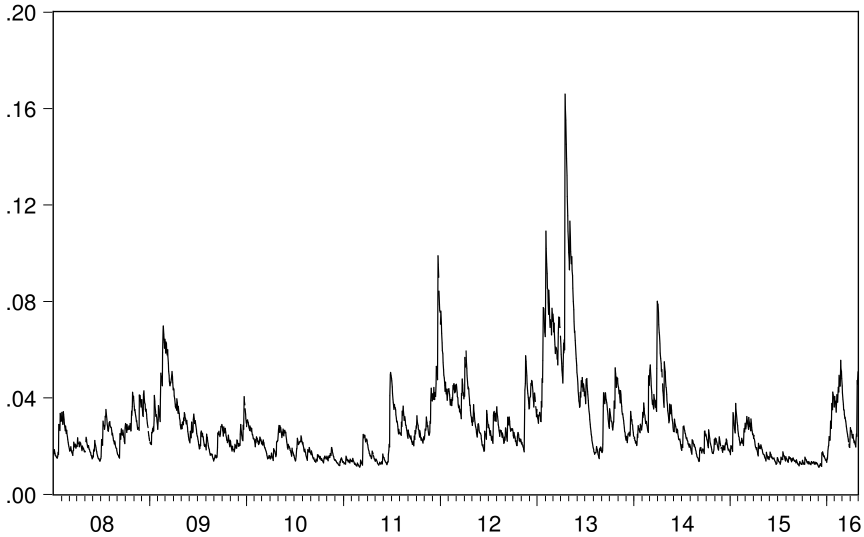


Figure 3: Forecasted conditional standard deviation of EUA Price returns

Section 3 we compiled a large data set of fundamental variables. However, in the analysis it turned out that only a small group of variables had a robust and significant impact on EUA prices.[2]

Table 1 presents descriptive statistics for the arguably most important fundamental drivers of the EUA price for the second (2008-2012) and third (2013-2016) trading period as well as for the full sample. Plots of the most important fundamental drivers can be found in Figure 8 in the Appendix. We focus on returns (log-differences) of the variables, because it turns out that the variables are integrated of order one and no robust evidence for cointegration can be found (see the discussion as well as Table 2 and Table 3 further below).

There are several time series that exhibit a small number of extreme observations. To obtain descriptive statistics that characterize the underlying distribution more reliable, we clean the series from observations that are larger than five standard deviations around the mean before calculating the descriptive statistics. In the third trading period there are three outliers in EUA returns. On the 1st of February 2013 the German Chancellor Angela Merkel supported plans of the minister of environment, which was perceived as support for the backloading proposal. The 16th of April 2013 coincides with the initial rejection of the

[2]Further below in Table 4 and in Table 8 in the Appendix, we show some selected estimation results using variables with robust impact jointly with groups of other potential fundamental drivers.

Table 1: Descriptive Statistics for the 2nd and 3rd trading period and the the full sample 2008-2016

| Trading Period II | Ann.Mean | Max. | Min. | Std.Dev. | Skew. | Kurt. | Obs. | # Outliers |
|---|---|---|---|---|---|---|---|---|
| EUA price | −14.1 | 0.11 | −0.12 | 0.03 | −0.23 | 4.90 | 1289 | 1 |
| Gas price | 0.8 | 0.12 | −0.07 | 0.02 | 1.00 | 10.44 | 1289 | 8 |
| Coal price | −4.2 | 0.09 | −0.10 | 0.02 | −0.23 | 9.77 | 1289 | 8 |
| CER price | −25.8 | 0.18 | −0.20 | 0.03 | −0.33 | 9.10 | 982 | 6 |
| Stoxx Utilities | −12.7 | 0.08 | −0.09 | 0.02 | −0.31 | 6.65 | 1289 | 3 |
| Stoxx B&R | −11.5 | 0.13 | −0.13 | 0.03 | −0.08 | 5.68 | 1289 | 3 |
| Trading Period III | | | | | | | | |
| EUA price | −1.7 | 0.13 | −0.17 | 0.03 | −0.45 | 6.92 | 856 | 3 |
| Gas price | −13.8 | 0.06 | −0.06 | 0.01 | 0.62 | 8.42 | 856 | 4 |
| Coal price | −12.3 | 0.04 | −0.05 | 0.01 | −0.49 | 6.85 | 856 | 4 |
| CER price | 39.6 | 0.69 | −0.85 | 0.10 | −0.86 | 22.77 | 856 | 6 |
| Stoxx Utilities | 3.3 | 0.04 | −0.04 | 0.01 | −0.16 | 3.68 | 856 | 1 |
| Stoxx B&R | −3.5 | 0.06 | −0.08 | 0.02 | −0.08 | 4.52 | 856 | 0 |
| Both Periods | | | | | | | | |
| EUA price | −8.8 | 0.13 | −0.13 | 0.03 | −0.19 | 5.7 | 2145 | 6 |
| Gas price | −5.1 | 0.09 | −0.08 | 0.01 | 0.52 | 8.7 | 2145 | 10 |
| Coal price | −6.5 | 0.08 | −0.08 | 0.01 | −0.20 | 10.7 | 2145 | 11 |
| CER price | −13.4 | 0.60 | −0.44 | 0.07 | −0.59 | 22.7 | 1838 | 9 |
| Stoxx Utilities | −7.1 | 0.07 | −0.08 | 0.01 | −0.22 | 5.9 | 2145 | 7 |
| Stoxx B&R | −7.1 | 0.10 | −0.11 | 0.02 | −0.05 | 5.7 | 2145 | 6 |

The second and third trading period include data from the periods May 2008 to December 2012 and January 2013 to May 2016, respectively. The column "# Outliers" shows how many observations were above above five standard deviations from the mean. Annualized mean returns are calculated as the growth rate of a variable over the respective period divided by the number of years of that period. All statistics are computed from the log-differences (returns).

backloading proposal by the European parliament. The third outlier May 3, 2013, is the first trading day after the actual emissions of companies under the EU ETS of the year 2012 were officially published by the European Commission. The numbers still indicated a surplus of certificates over realized emissions. However, the strong price increase on May 3 could indicate that market participants had expected an even higher surplus.

The descriptive statistics indicate the strong downward trend in EUA prices which is also visible in Figure 1. Accordingly, an investor would have lost around 14.1 percent on average when holding EUA certificates during the second trading period. The annualized mean return in the third trading period shows a somewhat smaller loss of –1.7 percent. Most of the fundamental variables also show negative (annualized) mean returns. Notably, the CER price experienced a steep decrease during the last one and a half years of the second trading period due to rising criticism and finally a partial ban of CER use as a substitute for EUA (also see the middle right panel of Figure 8 in the Appendix). The increase in CER returns during the third trading period reflects a small growth in CER prices, however, starting from almost zero during the third trading period.

In order to foster our understanding of the time series properties of the data we conduct unit root test of the levels and the first differences of the variables. We perform augmented Dickey-Fuller (ADF) tests for the full sample as well as for the second and the third trading period separately. Table 2 shows the ADF test results. For almost all variables we cannot reject the null hypothesis of a unit root in the levels of the variables, however, we can clearly reject this null hypothesis for the first differences of the variables. One exception is Stoxx utilities for which we can reject a unit root in the full sample and at least at the 5.1 significance level in the second trading period. However, in the third trading period we cannot reject a unit root in the levels of Stoxx utilities. Taken together, we can unambiguously classify all variables except Stoxx utilities as being integrated of order one.

Since the variables have unit roots it is interesting to test for a possible cointegrating relationship among the variables. To this end we perform Johansen and Juselius (1990) cointegration tests for various subsets of variables and adapting two different specifications for deterministic part of the model. The first specification only includes a constant in the cointegration relationships. The second specification contains a constant in the cointegration relationship and a constant in the first differences of the vector autoregressive model to take account possible linear trends in the variables. We perform the cointegration tests with four lags (as suggested by the AIC criterion) for the full sample (2008-2016) and for each of the

Table 2: Unit root tests for the full sample and the 2nd (2008-2012) and the 3rd (2013-2016) trading period

| | levels ADF-statistic | levels $p$-value | 1st differences ADF-statistic | 1st differences $p$-value |
|---|---|---|---|---|
| **Full sample (2008-2016)** | | | | |
| EUA price | -2.04 | 0.269 | -34.24 | 0.000 |
| Gas price | -1.41 | 0.578 | -16.19 | 0.000 |
| Coal price | -1.56 | 0.503 | -48.39 | 0.000 |
| CER | -0.82 | 0.812 | -42.38 | 0.000 |
| Stoxx Util. | -3.94 | 0.002 | -35.83 | 0.000 |
| Stoxx B&R | -2.66 | 0.082 | -46.69 | 0.000 |
| **Second trading period (2008-2012)** | | | | |
| EUA price | -2.04 | 0.268 | -34.24 | 0.000 |
| Gas price | -1.41 | 0.577 | -16.19 | 0.000 |
| Coal price | -1.58 | 0.490 | -37.62 | 0.000 |
| CER | 0.67 | 0.991 | -30.87 | 0.000 |
| Stoxx Util. | -2.86 | 0.051 | -28.00 | 0.000 |
| Stoxx B&R | -2.02 | 0.277 | -36.39 | 0.000 |
| **Third trading period (2013-2016)** | | | | |
| EUA price | -1.67 | 0.449 | -23.65 | 0.000 |
| Gas price | 0.00 | 0.957 | -30.03 | 0.000 |
| Coal price | -1.05 | 0.737 | -29.12 | 0.000 |
| CER | -1.83 | 0.366 | -36.04 | 0.000 |
| Stoxx Util. | -1.99 | 0.292 | -29.79 | 0.000 |
| Stoxx B&R | -1.93 | 0.318 | -27.91 | 0.000 |

The second and third trading period include data from the periods May 2008 to December 2012 and January 2013 to May 2016, respectively. The lag length in all ADF tests was chosen using the Schwarz Information Criterion with a maximum lag length of 25.

Table 3: Cointegration tests for the full sample and the 2nd (2008-2012) and the 3rd (2013-2016) trading period

| | **Variable specification** | | | | | | |
|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| EUA price | x | x | x | x | x | x | x |
| Gas price | x | x | | | x | x | x |
| Coal price | x | x | | | x | x | x |
| CER price | | x | | | x | x | x |
| Stoxx Util. | | | x | | x | | x |
| Stoxx B&R | | | | x | | x | x |
| **Full Sample** | *Model with constant in CI-relationship, no trend* | | | | | | |
| # of CI relat. | 0 | 0 | 2 | 1 | 0 | 1 | 2 |
| Trace-Statistic | 31.49 | 50.91 | 12.82 | 34.44 | 74.21 | 82.49 | 71.87 |
| 5% Critical value | 35.19 | 54.08 | 9.16 | 20.26 | 76.97 | 76.97 | 69.82 |
| $p$-value | 0.119 | 0.093 | 0.010 | 0.000 | 0.080 | 0.018 | 0.034 |
| | *Model with constant in both CI-relationship and in first diff.* | | | | | | |
| # of CI relat. | 0 | 1 | 2 | 2 | 1 | 2 | 2 |
| Trace-Statistic | 29.63 | 48.17 | 10.02 | 6.39 | 71.42 | 49.06 | 71.87 |
| 5% Critical value | 29.80 | 47.86 | 3.84 | 3.84 | 69.82 | 47.86 | 69.82 |
| $p$-value | 0.052 | 0.047 | 0.002 | 0.012 | 0.037 | 0.038 | 0.034 |
| **2008-2012** | *Model with constant in CI-relationship, no trend* | | | | | | |
| # of CI relat. | 0 | 0 | 2 | 1 | 1 | 0 | 0 |
| Trace-Statistic | 19.80 | 42.04 | 9.45 | 28.26 | 79.40 | 74.12 | 102.23 |
| 5% Critical value | 35.19 | 54.08 | 9.16 | 20.26 | 76.97 | 76.97 | 103.85 |
| $p$-value | 0.739 | 0.372 | 0.044 | 0.003 | 0.032 | 0.081 | 0.064 |
| | *Model with constant in both CI-relationship and in first diff.* | | | | | | |
| # of CI relat. | 0 | 0 | 2 | 2 | 1 | 1 | 1 |
| Trace-Statistic | 17.65 | 37.91 | 5.55 | 4.30 | 74.95 | 69.83 | 96.44 |
| 5% Critical value | 29.80 | 47.86 | 3.84 | 3.84 | 69.82 | 69.82 | 95.75 |
| $p$-value | 0.592 | 0.306 | 0.019 | 0.038 | 0.018 | 0.050 | 0.045 |
| **2013-2016** | *Model with constant in CI-relationship, no trend* | | | | | | |
| # of CI relat. | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Trace-Statistic | 30.12 | 36.69 | 12.37 | 12.34 | 60.93 | 55.21 | 80.64 |
| 5% Critical value | 35.19 | 54.08 | 20.26 | 20.26 | 76.97 | 76.97 | 103.85 |
| $p$-value | 0.159 | 0.640 | 0.416 | 0.419 | 0.438 | 0.674 | 0.598 |
| | *Model with constant in both CI-relationship and in first diff.* | | | | | | |
| # of CI relat. | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Trace-Statistic | 25.87 | 32.20 | 12.24 | 12.29 | 55.37 | 50.20 | 75.15 |
| 5% Critical value | 29.80 | 47.86 | 15.49 | 15.49 | 69.82 | 69.82 | 95.75 |
| $p$-value | 0.133 | 0.601 | 0.146 | 0.144 | 0.404 | 0.629 | 0.538 |

# of CI relat. shows the number of cointegration relationships detected i.e. the maximum number of cointegration relationships under the null hypothesis that could not be rejected at the 5 percent significance levels. Likewise, 5 % Critical Value shows the critical value for the null with the highest number of cointegration relationships that could not be rejected at the 5 percent significance levels. p-value shows the $p$-value corresponding to the trace test statistic and the null of the number of cointegration relationships shown in the corresponding row # of CI relationships. The lag length for all models is four.

two trading periods.[3]

Table 3 shows the cointegration test results. Including gas, coal and CER prices i.e. the short run drivers of EUA price as in column (1) and (2) we do not find evidence for cointegration in all (sub-)samples. The only exception is the test with full sample and a trend specification in column (2). When Stoxx utilities and Stoxx B&R are included in column (3) and (4) or in combination with the short run drivers in column (5), (6) and (7), we find mixed results regarding the number of cointegration relationships ranging from zero to two. Notably, for the third trading period we never detect one or more cointegration relationships. In summary, the cointegration tests do not support the existence of a stable cointegration relationship. Accordingly, we focus on analyzing the short run dynamics between the variables in the remainder of this study by focusing on the returns of the dependent and explanatory variables.

### 4.2. Assessment of Potential Drivers of the EUA Price

In order to assess whether reforms of the EU ETS and the political interventions of the third trading period had an effect on EUA price formation, we first establish a model containing the relevant drivers of the EUA price. The model will serve as a basis for testing for policy related structural breaks in the coefficients in the next section. As a first step we model the returns of the EUA price as a linear function of the returns of CO2 abatement related fundamentals. In our "core model" we include only the fundamental variables shown in Table 1.

The first column in Table 4 shows the OLS estimation results for our core model. All variables have the expected sign and all except the coal price have a significant effect on EUA returns. In line with the largest part of the literature (see e.g. Rickels et al. (2015) or Koch et al. (2014)), the $R^2$ is low fairly low (5.7 percent), indicating a low explanatory power of abatement related fundamentals for *daily* variation of EUA returns. As we found a strong degree of time varying volatility in EUA returns, we test for conditional heteroskedasticity in the residuals of the regression and find clear evidence for persistent variation in the variances of the residuals. The $F$-test statistic is 17.3 with a corresponding $p$-value close to zero. To account for conditional heteroskedasticity we therefore re-estimate the core model, where the errors are specified as a GARCH(1,1) process. The results are shown in the column two. The results of the GARCH model differ qualitatively from the OLS estimation results. The $t$-statistics tend to be substantially larger and the coefficient of coal price returns

[3] Alternatively, we used specifications with a higher lag length and also calculated the Maximum Eigenvalue statistic. The results were qualitatively very similar.

Table 4: Estimation results with EUA price returns as dependent variable

| | OLS | GARCH I | GARCH II | GARCH III |
|---|---|---|---|---|
| Gas price | 0.16*** | 0.190*** | 0.315*** | 0.319*** |
| | (4.42) | (8.40) | (9.92) | (10.03) |
| Coal price | -0.037 | -0.091** | -0.126*** | -0.120*** |
| | (-0.63) | (-2.41) | (-3.30) | (-2.97) |
| CER price | 0.033*** | 0.031*** | 0.028*** | 0.028*** |
| | (6.03) | (16.92) | (13.61) | (13.66) |
| Stoxx Util. | 0.176** | 0.039 | 0.016 | 0.077 |
| | (2.23) | (0.88) | (0.34) | (1.05) |
| Stoxx B&R | 0.155*** | 0.172*** | 0.142*** | 0.175*** |
| | (2.91) | (5.47) | (3.93) | (3.86) |
| d.Hydro NO | - | - | -0.007 | -0.006 |
| | - | - | (-1.27) | (-1.20) |
| d.Hydro FIN | - | - | 0.198 | 0.201 |
| | - | - | (1.11) | (1.12) |
| d.Wind DK | - | - | 0.027 | 0.030 |
| | - | - | (0.09) | (0.10) |
| d.Wind SE | - | - | 0.487 | 0.474 |
| | - | - | (1.38) | (1.35) |
| d.Wind UK | - | - | -0.236 | -0.228 |
| | - | - | (-1.03) | (-0.98) |
| d.Wind GER | - | - | 0.004 | 0.001 |
| | - | - | (0.08) | (0.02) |
| ESI | - | - | 0.000 | 0.014 |
| | - | - | (0.08) | (0.07) |
| Stoxx 600 | - | - | - | -0.090 |
| | - | - | - | (-0.63) |
| Stoxx 50 | - | - | - | -0.025 |
| | - | - | - | (-0.21) |
| $R^2$adj. | 0.057 | 0.054 | 0.051 | 0.050 |

[1] */**/*** attached to coefficients signify that the coefficient is significantly different from zero at the 10%, 5% or 1% level, respectively. t-values are given in brackets. All variables are transformed to returns (log-differences). “d.” indicates the first differences of the respective variables. Renewable energies variables are deseasonalized and detrended before first differencing.

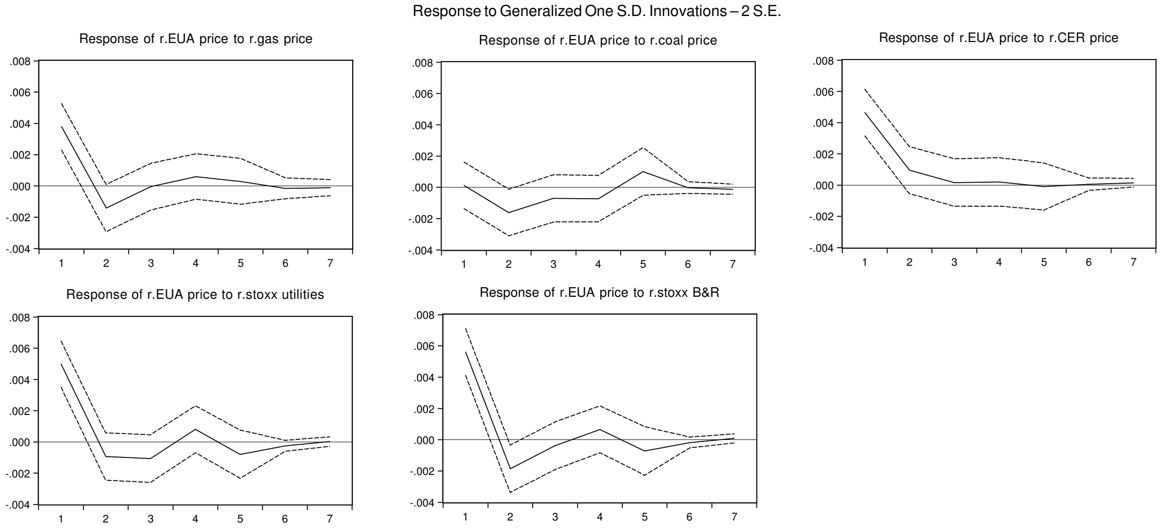


Figure 4: Generalized impulse responses of EUA returns with confidence bands obtained using 5000 Monte Carlo repetitions.

becomes significantly negative, in line with our economic reasoning. Taken together with the significantly positive coefficient of gas price returns, we now observe a statistically significant fuel switch. Furthermore, the Stoxx utility variable has lost its statistical significance.

In the literature a host of other explanatory variables is included in the regression in varying combinations. Accordingly, we also added different sets of abatement related explanatory variables to our GARCH(1,1) specification such as (de-seasonalized and de-trended) renewable energies and several variables representing general economic prospects. However, we were not able to find any robust, significant impact for these additional variables. In Table 4 we present two examples for models that include additional explanatory variables in column three ("GARCH II") and four ("GARCH III"). Several other models with different sets of additional explanatory variables are shown in Table 8 in the Appendix.

Our results suggest that neither the renewable energy variables nor the variables representing overall economic activity have a significant impact on EUA returns. Some of the renewable variables are strongly correlated and the low individual significance of these variables might be due to multicollinearity. Thus, we perform a likelihood ratio test for joint significance of the renewable energy variables in the "GARCH II" model. Given a test statistic of 6.06 and a corresponding $p$-value of 41 percent, we do not find evidence for joint significance of the renewable variables.

The regression model of EUA returns presented in Table 4 reveal the static responses of

EUA returns to changes in the fundamental drivers. In order to study the *dynamic* effects of EUA price formation, we employ a vector autoregressive (VAR) model containing the variables of the regression model presented in Table 4. The VAR model captures the dynamic relationship among all variables in the model. The generalized impulse response functions allows us to assess the dynamic responses of all variables beyond the contemporaneous relationships. Moreover, the VAR model allows us to apply Granger causality tests for assessing whether lagged changes in potential EUA price drivers have a statistically significant impact on EUA returns and vice versa.

Figure 4 shows the responses of EUA returns to shocks in the returns of gas, coal and CER prices as well as Stoxx utilities and Stoxx B&R. The VAR models are estimated with a lag length of four, however, other lag length choices produce very similar results. The impulse responses show that EUA returns respond to shocks in potential short run drivers as expected. Whereas EUA returns respond positively to shocks in gas price returns, they react negatively to shocks in coal price returns. The response, however, is only significantly different from zero in the first period for gas shocks and in the second period for coal shocks. Shocks in CER returns only show a significantly positive response in the first period. Similarly, the shocks in the long run fundamentals i.e. returns of Stoxx utilities and Stoxx B&R only lead to a significant positive response in EUA returns in the first period.

Figures depicting the impulse responses of gas, coal and CER price returns as well as Stoxx returns can be found in the Appendix (Figures 9, 10, 11, 12 and 13). Gas returns respond positively significant to all variable shocks except CER returns. The only significant response of coal returns is to gas returns. The response is positive and significant for two periods. CER returns respond significantly to shocks in EUA prices only. As expected for substitutes the response is positive. Stoxx utilities respond significantly positive to shocks in EUA, gas, and stoxx B&R returns, respectively. Similarly, Stoxx B&R respond significantly positive to shocks in EUA, gas, and Stoxx utilities returns, respectively. The results for the Granger causality tests are show in Table 9 in the Appendix.

In contrast, to the impulse responses the Granger causality tests do not find evidence for a statistically significant dynamic relationship between the lags of the explanatory variables and EUA returns. However, coal returns seem to be causal for gas prices and vice versa. Further, Stoxx utilities is identified as a significant predictor of coal returns. These mixed and negligible findings can be interpreted as evidence that the information in the fundamental drivers is fully incorporated within one month such that no dynamic effects needs to be addressed in our further analysis.

### 4.3. Has the Market Design of the 3rd Trading Period Changed EUA Price Formation?

As explained in Section 3, a successful reform of the market design should affect the systematic price formation represented by the coefficients of the fundamental drivers. Accordingly, we expect to detect a structural change in the coefficients of the reduced form models of Table 4 around the end of the second trading period or the beginning of the third trading period. Accordingly, we test the null hypothesis of no structural break in the coefficients using an Quandt-Andrews breakpoint test. In order to account for the conditional heteroskedasticity, we estimated the core model with weighted least squares using the estimated GARCH variances for the weighting scheme. This test detects structural breaks with an unknown break date by calculating the likelihood ratio test statistic for all potential break dates. The date with the highest test statistic ($MaxF$) is the Maximum Likelihood estimate of the break date. The critical values for the $MaxF$ statistic is presented in Andrews (1993). Our value of the test statistic is 179.6 clearly rejecting the null hypothesis at the one percent significance level. As shown in Figure 5, the test statistic reaches its maximum at September 3, 2012. Accordingly, the test clearly indicates a change in EUA price formation only 4 months before the start of the third trading period. This break date suggest that market participants anticipated the important changes introduced in the third trading period already four periods before new design of the trading period were introduced.

In order to analyze the changing impact of the fundamental variables before and after the structural break, we interact the explanatory variables with a permanent shift dummy variable with a value of zero before Sep 3, 2012 and one afterwards. We add these interaction terms to the core model as used before in the first two columns of Table 4). In this specification, the (non-interacted) coefficients of the fundamental variables represent their respective impact before the structural break. The coefficients of the interaction terms show the change in the coefficients of the respective fundamental variables due to the structural break. The results are shown in Column one ("Pre-Break") and three ("Change") of Table 5. In order to determine the size of the coefficients and their significance after the break we create a new variable which we use instead of the aforementioned structural interaction terms. The new variable is constructed as the difference between the original variable, say r.Gas price, and the structural break interaction term as defined above. Hence, if I_ Gas price is the structural break interaction term for the fundamental variable Gas price, we obtain the new variable as I2_ Gas price = Gas price - I_ Gas. When we include this new variable together with the original fundamental variable in the model, we can interpret the coefficient of the original variable as the impact of the original variable after the structural

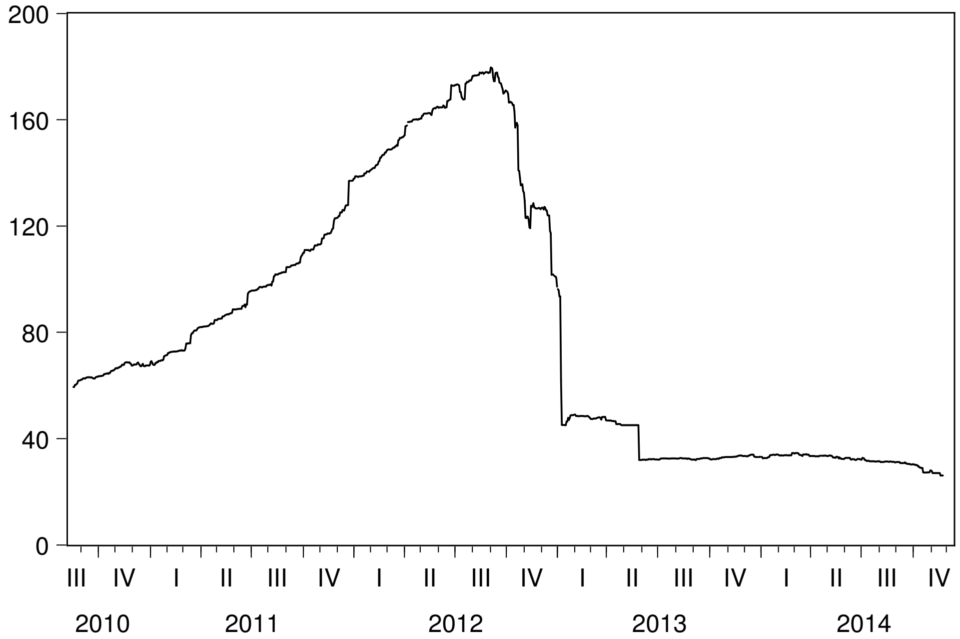


Figure 5: Likelihood ratio statistic for structural break test

break and the coefficient of the new variable shows the change in the coefficient compared to the situation before the break. For conciseness, we only show the impact of the fundamental variables after the break in column two ("Post-Break") of Table 5.

According to the "Pre-break" column of Table 5 only gas price returns and CER price returns had a significant impact before the structural break. This low significance of major fundamentals such as coal and Stoxx returns for EU ETS relevant sectors is in line with earlier studies that found no significant impact of many variables deemed as major drivers of the EUA price (see Section 1). The column "Change" reveals that the impact of all short run drivers of EUA price i.e. the gas, coal and CER price returns changed strongly and significantly due to the break. The impact of long run drivers such as the returns of Stoxx utilities and Stoxx B&R did not change in any significant way. According to the column "Post-Break", the coefficient of gas returns is almost eight times higher than before the break. Coal returns gained significance and the expected negative sign only after the break. CER returns while still significant dramatically lost in terms of impact. This can be explained by the temporary ban and following restrictive re-admission of CER in the EU ETS in the years around the break.

The returns of Stoxx utilities representing the longer term economic outlook of the util-

Table 5: GARCH(1,1) Estimation results with EUA price returns as dependent variable

| Explanatory Variables | Pre-Break | Post-Break | Change |
|---|---|---|---|
| Gas price | 0.043** | 0.324*** | 0.280*** |
| | (2.52) | (7.67) | (6.18) |
| Coal price | 0.030 | -0.206*** | -0.237*** |
| | (1.33) | (-4.14) | (-4.30) |
| CER price | 0.881*** | 0.017*** | -0.863*** |
| | (79.82) | (5.71) | (-74.96) |
| Stoxx Util. | 0.027 | 0.124** | 0.096 |
| | (0.84) | (1.97) | (1.36) |
| Stoxx B&R | 0.028 | 0.060 | 0.031 |
| | (1.36) | (1.26) | (0.61) |

*/**/*** attached to coefficients signify that the coefficient is significantly different from zero at the 10%, 5% or 1% level, respectively. $t$-values are given in brackets. All variables are transformed to returns (log-differences).

ities sector are significant only after the break. The returns of Stoxx B&R representing the economic outlook of basic materials and resources sector exhibit no significant impact on EUA returns when the structural break is accounted for. Taken together, in the second trading period we find a low or even no impact of variables that in the literature are seen as the most relevant potential drivers of EUA prices. The impact of most of these variables on EUA prices only became strong just before the third trading period. We interpret these findings as evidence that the changes of market of the third trading period had a decisive impact on EUA price formation and tied movements of the EUA price much closer to movements of variables representing marginal abatement costs. Hence, our results suggest that CO2 abatement was more efficiently implemented via the EU ETS in the third trading period than before.

To illustrate the differences in price formation before and after the structural break, we simulate a counter-factual EUA price development in the period after the structural break under the assumption that price formation has not changed i.e. was the same as before the break. Accordingly, we estimate the parameters of the core model (column "GARCH I" in Table 4) using data solely from the period before the structural break and employ the estimated parameters to fit EUA price returns and the corresponding EUA prices for the period after the structural break.[4] Figure 6 shows the actual and the simulated counter-factual

[4] The fitted EUA prices $\hat{p}_t$ were obtained from the fitted EUA returns $\hat{r}_t$ using $\hat{p}_t = e^{(\hat{r}_t + log(\hat{p}_{t-1}))}$ where

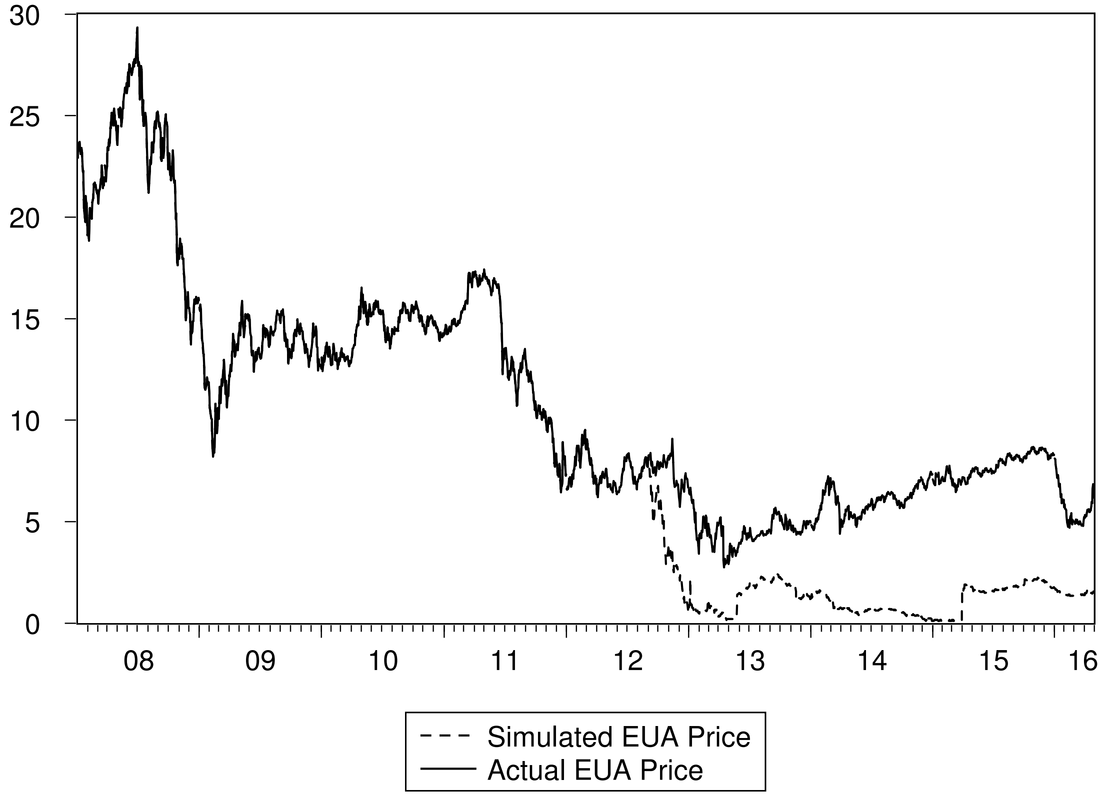


Figure 6: Actual EUA prices and simulated EUA price assuming pre-break price formation

EUA prices. Under the pre-break price formation pattern EUA prices turn out much lower in the latter part of the sample than under the post-break price formation pattern. Hence, EUA prices in the third EU ETS trading period would have turned out even much closer to zero if price formation had not changed. We interpret this as evidence that the improved market design of the third trading period indeed contributed to stabilizing prices at politically desired higher levels than without the market design changes. A stronger impact of variables during the third trading period suggests a better functioning EUA market. Moreover, the market design and the corresponding price formation pattern of the third trading period also contributed to stabilize EUA prices at comparatively high levels - something that is clearly desired by most policy makers.

$\hat{p}_0 = p_0$ is the actual EUA price measured at the last day before the structural break.

### 4.4. Volatility Effects of EU ETS market design changes

As explained in Section 3, a change in the market rules may not only change the formation of EUA prices, but can also have the negative side effect of temporarily increasing uncertainty and, thus, price volatility, since market participants have to become familiar with the new market environment. However, a change in market design that makes future price developments more predictable might also decrease the uncertainty of market participants and, in turn, could lead to decreasing EUA price volatility. In order to investigate how uncertainty, interpreted as conditional price volatility, has changed as a response to changes in the market design, we analyze the conditional volatility of the EUA price returns obtained from the estimated GARCH process. The model is specified as

$$y_t = x_t'\beta + u_t$$
$$\sigma_t^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta\sigma_{t-1}^2 + z_t'\gamma$$

where $u_t = \sigma_t\varepsilon_t$, $\varepsilon_t \sim \mathcal{N}(0, \sigma^2)$, $x_t$ is a vector of the fundamental drivers and $z_t$ is an vector of dummy variables representing the political interventions such that $z_t'\gamma$ represents the shift in the conditional variance due to the events represented by the dummy variables. The first column of Table 6 (upper panel) shows the GARCH parameter estimates for the variance equation of our core model "GARCH I" from above (see column two in Table 4 for the coefficient estimates for the corresponding mean equation). The sum of the GARCH parameters is close to one indicating a high persistence of variance shocks. In order to analyze how the conditional variance of EUA returns has developed over time, we use the estimated parameters of the variance equation to calculate the one-step ahead forecast of the conditional standard deviation of EUA price returns. Figure 7 exhibits a plot of the forecasted conditional GARCH standard deviation for trading period two and three. The plot shows a very strong increase in volatility at the start of trading period three and suggests an unsteady downward trend during phase three.

To evaluate whether the overall higher volatility in trading period three finds further statistical support, we include a permanent shift (Column (2)), a trend shift (Column (3))or both (Column (4)) to the variance equation of the "GARCH I" model shown in the upper panel of Table 6. The permanent shift dummy has a value of zero before the structural break Sep 3, 2012 and a value of one afterwards. The trend shift variable has a value of zero before Sep 4, 2012 and increases by one on each following day. The estimation results in the columns (2) and (3) in the upper panel of Table 6 do not show a highly significant permanent shift in the conditional volatility, nor a significant downward trend if both variable types

Table 6: Estimation results for the variance equation of the GARCH(1,1) with EUA price returns as dependent variable

| Models without accounting for structural break in mean equation | | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| $\alpha_0$ | 7.79*** | 7.03*** | 8.20*** | 9.24*** |
| | (4.63) | (4.21) | (4.55) | (4.72) |
| $\alpha_1$ | 0.142*** | 0.144*** | 0.142*** | 0.148*** |
| | (14.14) | (13.74) | (14.03) | (13.28) |
| $\beta$ | 0.863*** | 0.859*** | 0.863*** | 0.847*** |
| | (94.54) | (85.7) | (93.61) | (74.58) |
| Perm. Shift | - | 4.20* | - | 35.4*** |
| | - | (1.70) | - | (4.44) |
| Trend Shift | - | - | -0.001 | -0.046*** |
| | - | - | (-0.49) | (-4.49) |
| Models with structural break interaction term in the mean equation | | | | |
| | (5) | (6) | (7) | (8) |
| $\alpha_0$ | 2.08*** | 2.68*** | 2.22*** | 3.12*** |
| | (8.86) | (9.32) | (9.14) | (9.51) |
| $\alpha_1$ | 0.155*** | 0.161*** | 0.156*** | 0.164*** |
| | (14.62) | (14.73) | (14.79) | (14.51) |
| $\beta$ | 0.862*** | 0.839*** | 0.855*** | 0.827*** |
| | (109.94) | (87.72) | (103.64) | (81.07) |
| Perm. Shift | - | 12.9*** | - | 53.30*** |
| | - | (4.65) | - | (6.14) |
| Trend Shift | - | - | -0.007** | -0.058*** |
| | - | - | (2.21) | (-5.19) |

*/**/*** attached to coefficients signify that the coefficient is significantly different from zero at the 10%, 5% or 1% level, respectively. t-values are given in brackets. For the readers' convenience the constant as well as the coefficients of the permanent shift dummy and the trebd shift are multilied by $10^6$. All variables are transformed to returns (log-differences).

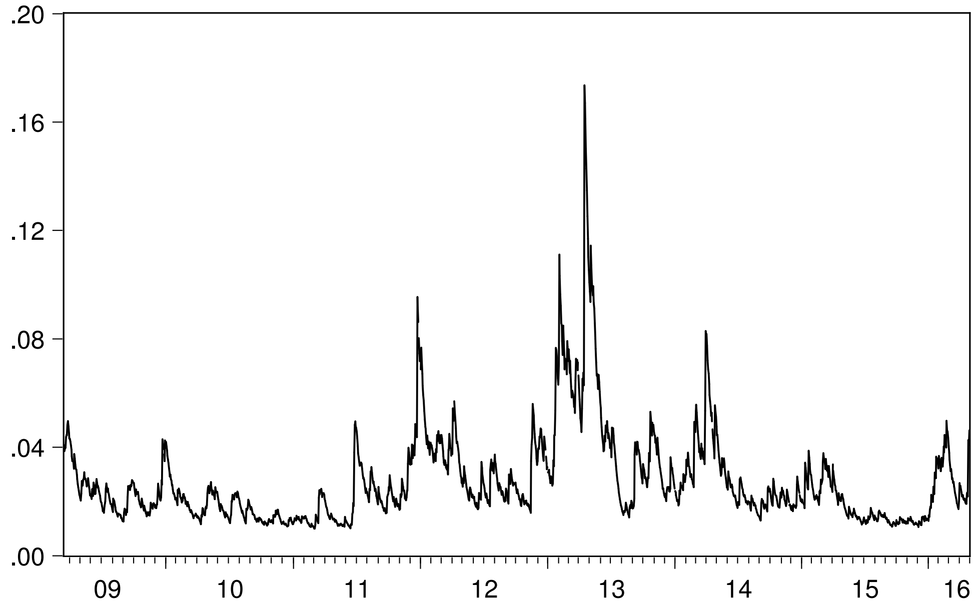


Figure 7: Forecasted conditional standard deviation of EUA price returns of "GARCH I" model of Table 4

are included separately. In contrast, the results of column (4) exhibit a significant increase in volatility and a clear downward trend in volatility after the structural break associated with phase three. This implies that the variances jump up in September 2012 and gradually decline in the subsequent time periods.

The GARCH models in the upper panel have ignored the structural break in the parameters of the mean equation. We account for the structural break by re-estimating the GARCH models with a structural break interaction term included in the mean equation (see Table 5 above for the coefficient estimates of the mean equation). The corresponding parameter estimates for the variance equation are shown in the lower panel of Table 6. Column (5) shows the parameter estimates when no dummy variables are included in the variance equation. Column (6), (7) and (8) show the results when the permanent shift dummy, the trend shift or both variables are included. Both the permanent shift dummy as well as the trend shift are significant in all model specifications. Hence, the estimation results provide strong evidence for an increase in volatility and price uncertainty at the start of the third trading period followed by a downward trend.

Taken together our empirical results support the idea that a change in the market design leads to increased uncertainty among market participants and a corresponding high volatility in EUA prices that cannot be explained by variations in the fundamental drivers of the EUA price. Moreover, the initial surge in volatility after a change in the EU ETS market design was followed by a clear negative trend over the remainder of the third trading period. We interpret this as evidence of market participants getting familiar and adjusting to the new market environment over time. Hence, the EU ETS market reforms in the wake of the third trading period illustrate an important trade off: On the one hand, a market reform may improve the functioning of a market – in the case of the EU ETS by making the EU ETS price more reactive to its abatement cost related fundamental drivers. On the other hand, a change in the market design leads at least temporarily to an increased uncertainty among market participants and thereby increases uncertainty and the corresponding volatility. Policy makers should therefore carefully balance the benefits of a better market design against the disadvantages associated with higher price volatility.

### 4.5. Assessing the Role of Policy Interventions

Koch et al. (2016) and Conrad et al. (2012) find empirical evidence for a strong role of (expected) policy interventions for the development of EUA prices. Thus, it is necessary to evaluate whether our findings are robust to the inclusion of variables reflecting expectations about future policy interventions. Vice versa, we can assess whether we find support for the existing results in the literature when accounting for conditional volatility and for structural breaks in the mean equation of EUA returns.

We use and extend the list of policy events collected in Koch et al. (2016). We characterize the policy events as belonging to a political category. We group the policy events similar to Koch et al. (2016) into events that a) potentially influence future certificate supply and market design only in the long run i.e. only after the year 2020 and b) events that most likely have a potential impact before the end of the third trading period. We sub-dived the latter group of events further into two prominent subtopics that were on the political agenda in recent years. These topics comprise the backloading debate that is also analyzed in Koch et al. (2016) and the events around the introduction of the market stability reserve. The full description of political events and their categorization are shown in Table 11 in the Appendix. For each policy event we construct an impulse dummy that is one for event period and zero otherwise. As our econometric model is specified in terms of log-differences, the coefficient of an impulse dummy represents a permanent shift in the levels of the dependent variable – a reasonable specification given that all variables are integrated of order one and exogenous shocks therefore have a permanent impact.

Table 7 presents the estimation results for the core model and for the models with

Table 7: Estimation results when policy dummies are included

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Gas price | 0.190*** | 0.191*** | 0.192*** | 0.044** | 0.043** | 0.044** |
| Coal price | −0.096** | −0.086** | −0.092** | 0.031 | 0.030 | 0.031 |
| CER price | 0.031*** | 0.026*** | 0.031*** | 0.882*** | 0.882*** | 0.881*** |
| Stoxx Util. | 0.040 | 0.049 | 0.041 | 0.028 | 0.027 | 0.026 |
| Stoxx B&R | 0.167*** | 0.167*** | 0.167*** | 0.028 | 0.029 | 0.029 |
| I_ Gas price | | | | 0.259*** | 0.214*** | 0.275*** |
| I_ Coal price | | | | −0.237*** | −0.189*** | −0.233*** |
| I_ CER price | | | | −0.863*** | −0.868*** | −0.864*** |
| I_ Stoxx Util. | | | | 0.104 | 0.119 | 0.093 |
| I_ Stoxx B&R | | | | 0.021 | 0.023 | 0.034 |
| LR test p-values for joint significance of policy dummies | | | | | | |
| Backloading | 0.000 | | | 0.000 | | |
| MSR | | 0.000 | | | 0.000 | |
| Long term | | | 0.656 | | | 0.989 |

Upper panel: */**/*** attached to coefficients signify that the coefficient is significantly different from zero at the 10%, 5% or 1% level, respectively. Lower Panel: $p$-values for LR test

structural break interaction terms "I_". For conciseness, we only show the results of $F$-tests for joint significance of the set of dummy variables belonging to the backloading debate, the market stability reserve (MSR) debate and the debate on long term issues. For the detailed results including the coefficients and significance levels of all individual dummy variables, please see Table 10 in the Appendix. The estimation results are qualitatively as well as quantitatively robust with respect to the inclusion of policy dummies.[5] The dummy variables belonging to the backloading and the market stability reserve are jointly highly significant, whereas the policy dummies of the long term issues are not significant. Inspection of Table 10 in the Appendix also reveals that in contrast to Koch et al. (2016) only two backloading dummies and one or two long term policy dummies are individually significant. Hence, as conditional volatility plays a strong role for EUA prices, researcher should account for both GARCH effects as well as structural breaks when studying the impact of policy interventions on EUA prices.

[5] We also estimated specifications containing more or even all of the dummies described in Table 11 in the Appendix. However, only the dummies shown in Table 10 in the Appendix tend to have significant coefficients.

## 5. Conclusion

Politically designed markets, such as central bank money tenders or markets for pollution control, face two major challenges related to any policy intervention. The first is the improvement of the functioning of the respective market design, i.e. the economic efficiency of the policy instrument. The second challenge is that each policy intervention in supply or demand as well as the market design will induce (temporary) uncertainty about the firms' optimal bidding strategy. A prominent example for a market were regulatory changes have been intensively discussed in economic literature is the world's largest cap-and-trade system, the European Emissions Trading Scheme for CO2 emission allowances. The European Commission has changed the EU ETS market design several times in recent years in order to align the market outcomes with political targets and to improve economic efficiency of CO2 reduction. The most prominent change went along with the transition from the second to the third trading period. In this transition, the formerly free allocation of allowances was transformed to an auctioning system. A true single cap for the EU has been introduced and banking of allowances has been permitted. Within the current third phase, additional changes have been made. The changes can be attributed to two different kinds: backloading and updates of the allowance cap.

In this paper, we have analyzed whether these market interventions have improved the functioning of the market. Therefore, we develop a model for relating EUA prices to fundamental drivers of actual abatement costs. We found that gas and coal prices have significantly gained explanatory power for the EUA price at the end of the second trading period. Especially the impact of gas prices has increased dramatically. Similarly, coal prices have become significant and show – in accordance with the notion of fuel switch – the expected negative sign. These important features emerges at the end of the second trading period only. Accounting for conditional heteroskedasticity, we find a structural break in the relationship between the EUA price and its fundamental drivers around that time. Variables that are related to short-run marginal abatement cost show their expected significant effect on EUA prices only from the time of the structural break onwards. Similarly, the sectoral Stoxx index for utilities only becomes significant after the structural break in September 2012.

We interpret the strengthening of the relationship between EUA prices and the fundamental drivers as an indication of improved market conditions. Hence, the end of the second trading period and the advent of the market design changes of the third trading period mark the beginning of superior EUA price formation. In a counterfactual analysis, we were able to show that prices would have been much lower than the observed prices provided the market characteristics governing the second phase would remain unchanged. One might argue that not only did the change in market design increase the functioning of the market, but it also had a positive effect on the level of the CO2 price – something that is desired by most policy makers. This, in turn, indicates that previous regulation was insufficient to establish efficient abatement incentives.

Changes of the market design may have increased regulatory uncertainty. Authors like Koch et al. (2016) and Hitzemann et al. (2015) have identified serious price movements following regulatory announcements. To analyze additional uncertainty due to market policy interventions, we investigated EUA price volatility in relation to political reforms and announcements by including dummy variables for political events that have changed expectations about EU ETS market design. In contrast to Koch et al. (2016) we find considerably less evidence for the role of political and regulatory events when conditional heteroskedasticity is accounted for. Nevertheless, our analysis of EUA returns has shown that volatility was extremely high during the first months of the third trading period. The transition period of the third phase is interpreted as a time where market agents tentatively adapt to the adjusted market conditions. New participants, new rules and the end of free allocation seem to have been a challenge for emissions traders, making it necessary to collect new information and adjust their EUA portfolios.

Overall, our analysis illustrates both the advantages and the drawbacks of market design changes. On the one hand, we see an improved price formation and, thus, an arguably better functioning EUA market. On the other hand, the change in market design has increased price volatility during an initial phase, indicating costly adaptations of the new regime. The takeaways from our results for economic policy advice is threefold. First, regulatory interventions which are able to reveal actual abatement cost, i.e. increase the explanatory power of fundamentals for allowance prices, are an effective instrument to increase the intended function of the allowance market and are worthwhile to be introduced. However, market design changes should be communicated in advance to prepare market participants. This communication should be less erratic than in the past, but more purposeful and consistent in the future. A third political aspect deals with the complexity of changing a European cap-and-trade system influenced by various national governments. If this complexity reduces long-run regulatory credibility and, by that, induces uncertainty, it might undermine long-term abatement incentives. Then, as Koch et al. (2016) suggested, an alternative to emissions trading, for instance a CO2 tax, should be considered.

Future research should intensify the analysis of optimal regulatory communication. Analogous to Central Bank communication, a special focus should be put on the communication process and timing of market-redesigns. Regarding the evaluation of price formation within the EU-ETS, abatement cost curves should be analyzed on a sectoral level hereafter. With an increasing heterogeneity of market participants, fundamental drivers of abatement cost might become more diverse as well, making market efficiency analysis more difficult in future.

Beyond the focus of this paper, there are additional other aspects which provide opportunities for future research. An interesting and important strand of literature has for instance addressed the financial economics aspects of the EU-ETS, so called 'carbon finance' focussing on the role of market uncertainty and market participants' expectations (Hintermann et al. (2016)). Financial economics has developed thorough theoretical models on how to manage uncertainty and value options. Especially the option approach has been identified as a well-suited instrument to understand market agents' behaviour: any emission allowance can be interpreted as an option whether to invest into abatement technologies (and sell the allowance) or use the allowance for compliance. It is therefore an option which allows the agent to postpone the abatement investment until uncertainty about optimal abatement decisions is reduced (Chao and Wilson (1993); Chesney and Taschini (2012)). If this real option has a positive value, however, it should be reflected in the allowance price. Then, however, allowance prices would not be equal as true marginal abatement costs. Also, allowance prices might be positive even if the emissions cap is expected to be non-binding (Chesney and Taschini (2012)). Furthermore, the efficiency of the permits market, market participation by smaller firms and efficiency biases due to transaction costs are not yet fully understood. Hintermann et al. (2016) suggest a deeper analysis of the efficient amount of trading, taking initial permit distribution and the uncertainty of demand, technological progress in production and innovation in abatement technologies into account.

A third strand of previous and future research focuses on the industrial organisation of the permits market, i.e. issues of market power and market design. The exertion of market power can especially occur when high transaction costs prevent agents from market participation. Interestingly, market power in the EU ETS is related to free allocation of allowances. From an economic perspective, cost pass-through even of cost-free but marketable inputs is not related to market power, but simply windfall profits (Sijm and Chen (2006)). However, Hintermann (Hintermann (2015)) has shown that large electricity companies have an interest in high allowance prices even when they are net buyers if they receive a large amount of allowance for free. Then, these companies holding excess allowances instead of trading them is consistent with strategic price manipulation, i.e. the exertion of market power. However, previous research has addressed the market power issue primarily theoretically or experimentally, with the notable exemption of Hintermann (Hintermann (2015)), who indirectly identified strategic allowance price manipulation. Yet, direct empirical evidence is not existent.

Summing up, three different future research areas might be identified (Hintermann et al. (2016)). The first one addresses the question whether the emissions markets serve their economic purpose and deliver least cost abatement solutions. This question is also crucial from a methodological point of view. When additional sectors and production technologies enter the permits market, the marginal abatement cost curve might change. But even without changes of market agents, optimal abatement strategies might alter due to technological change. The power sector has experienced fundamental changes due to the deployment of new and renewable generation technologies. This, however, might change price dynamics and also price formation in general. New methodological approaches allowing for time-varying price relations and dynamics on input markets could be an interesting field of future research (see Hintermann et al. (2016)). This holds also true for the analysis of interactions with other climate policy instruments and other regional permits markets. The second important question which should be analyzed deals with carbon finance aspects and the financial analysis of the permits market in particular. Research which relates finance models with the theoretical considerations from environmental economics seem to be not only promising from an academic perspective but also capable of explaining positive allowance prices even in a situation of oversupply. A third crucial future issue both for academia and politics is the analysis what could be done to improve future market functioning. Therefore, an 'interdisciplinary' approach seems to be most promising. Models from environmental and energy economics, industrial organization and finance have to be combined to simultaneously address questions of rational abatement, proper market design and uncertainty appreciation. With its excellent researchers in any of these fields, the faculty of management, economics and social sciences at the University of Cologne could by a successful future actor in improving permits markets' design.

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## Appendix

Table 8: Estimation results with EUA price returns as dependent variable

| Variable | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| r.Gas price | 0.281*** | 0.342*** | 0.339*** | 0.339*** | 0.320*** |
| r.Coal price | -0.119*** | -0.138*** | -0.136*** | -0.137*** | -0.141*** |
| r.CER price | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| r.Stoxx Util. | 0.086 | 0.116 | 0.114 | 0.113 | 0.149 |
| r.Stoxx B&R | 0.115** | 0.117 | 0.117 | 0.119 | 0.094 |
| r.Stoxx 50 | -0.042 | 0.109 | 0.110 | 0.113 | 0.117 |
| r.Stoxx 600 | -0.085 | -0.140 | -0.140 | -0.144 | -0.156 |
| r.Stoxx for. & pap. | 0.081* | 0.013 | 0.012 | 0.011 | 0.031 |
| r.Stoxx oil & gas | -0.011 | -0.031 | -0.029 | -0.029 | -0.070 |
| d.Hydro FIN | 0.000 | -0.001 | -0.001 | -0.001 | -0.001 |
| d.Hydro NO | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| d.Wind DK | -0.026 | -0.041 | -0.040 | -0.040 | -0.049 |
| d.Wind SE | 0.033 | 0.039 | 0.039 | 0.036 | 0.034 |
| d.Wind UK | 0.001 | -0.005 | -0.005 | -0.008 | -0.007 |
| d.Wind GER | 0.011** | 0.011 | 0.011 | 0.011 | 0.001 |
| d.Solar SE | | 0.015 | 0.015 | 0.015 | 0.012 |
| d.Solar GER | | 0.000 | 0.000 | 0.000 | 0.000 |
| r.ESI | | | -0.114 | -0.115 | -0.207 |
| yield spread | | | | 0.000 | 0.000 |
| r.Load | | | | | 0.021 |

[1] */**/*** attached to coefficients signify that the coefficient is significantly different from zero at the 10%, 5% or 1% level, respectively. "r." indicates the returns and "d." the first differences of the respective variables. Renewable energies variables are deseasonalized and detrended before first differencing.

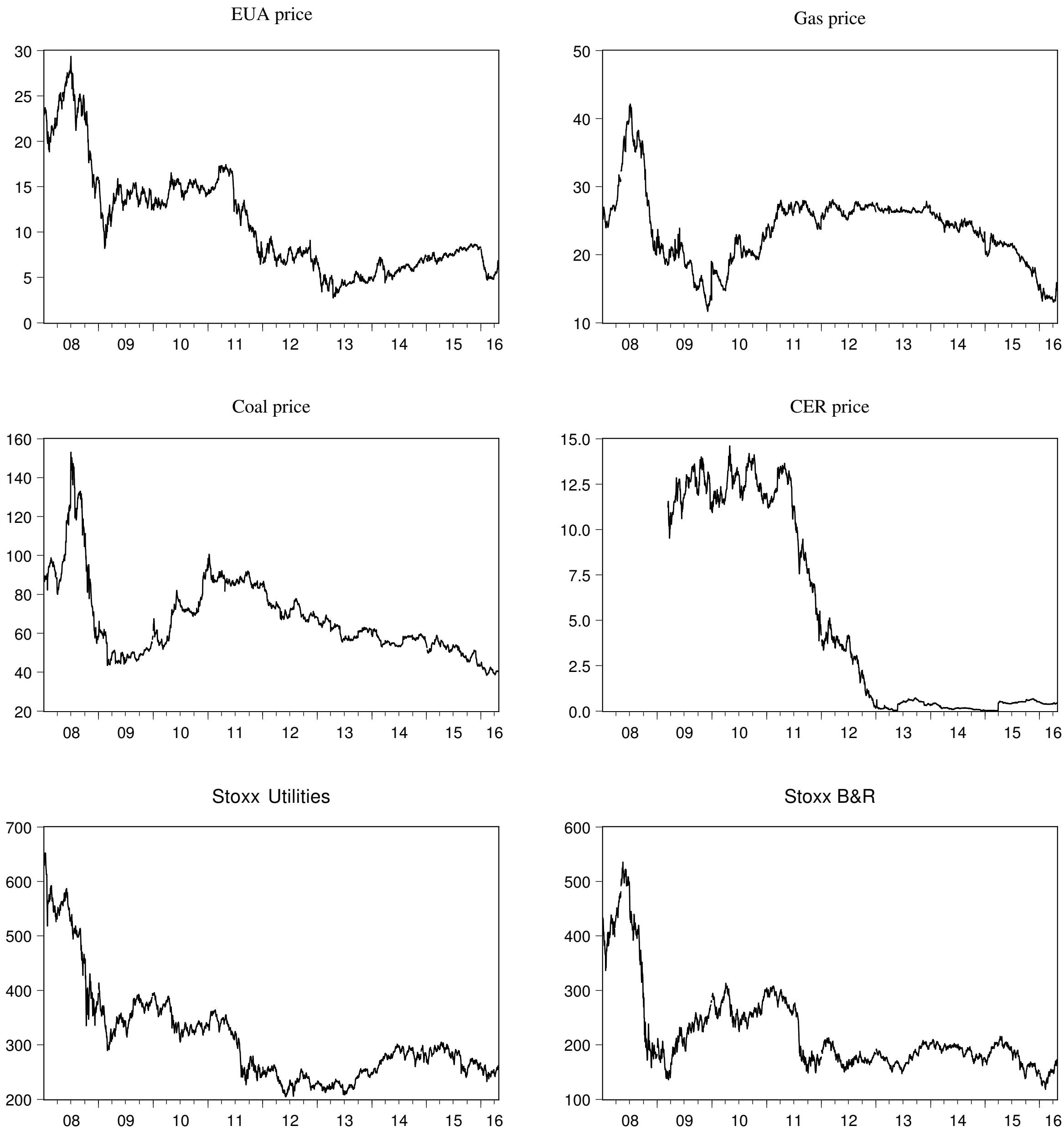


Figure 8: Plots of variables over the 2nd and 3rd trading period of the EU ETS

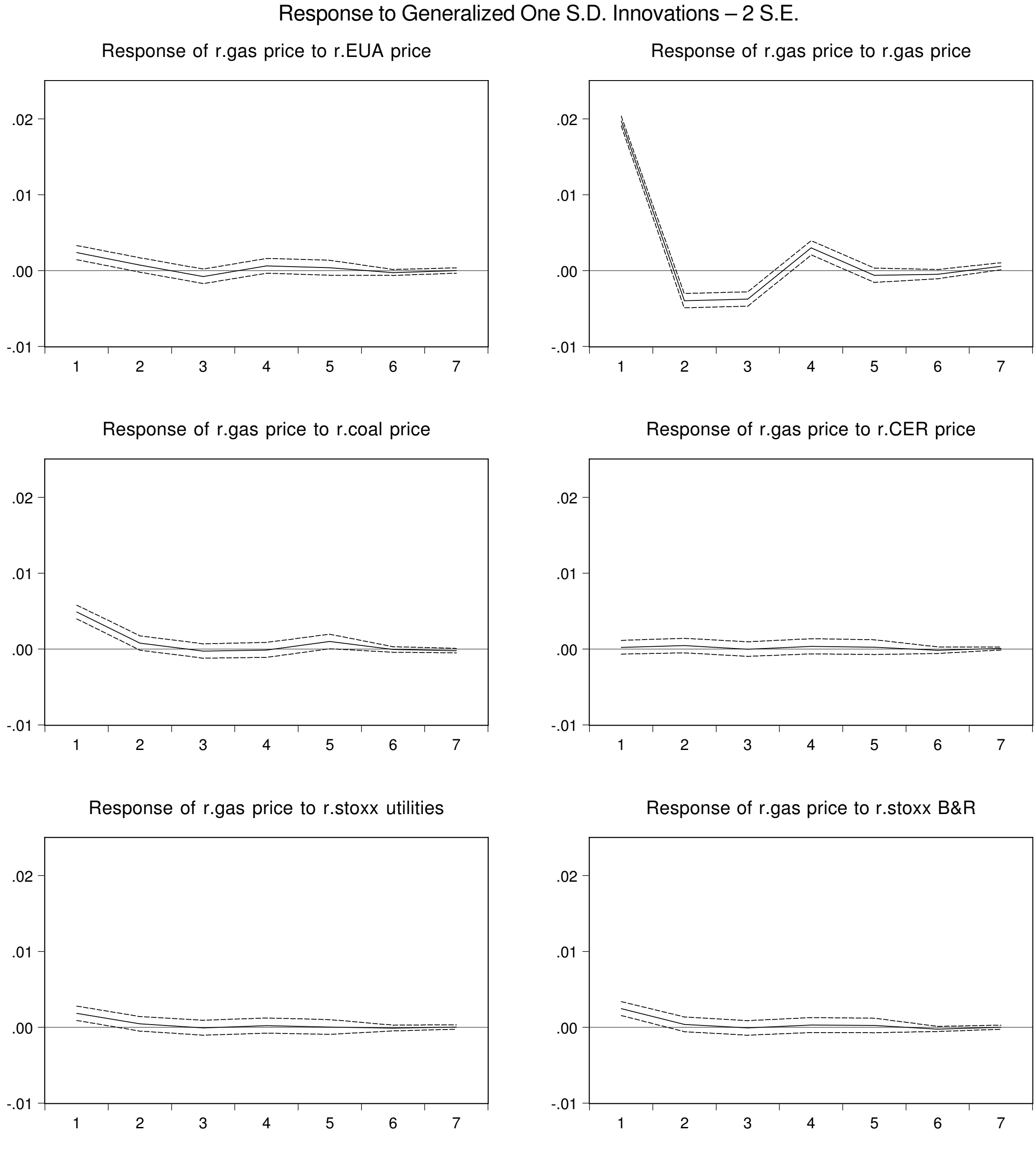


Figure 9: Generalized impulse responses of gas price returns with confidence bands obtained using 5000 Monte Carlo repetitions.

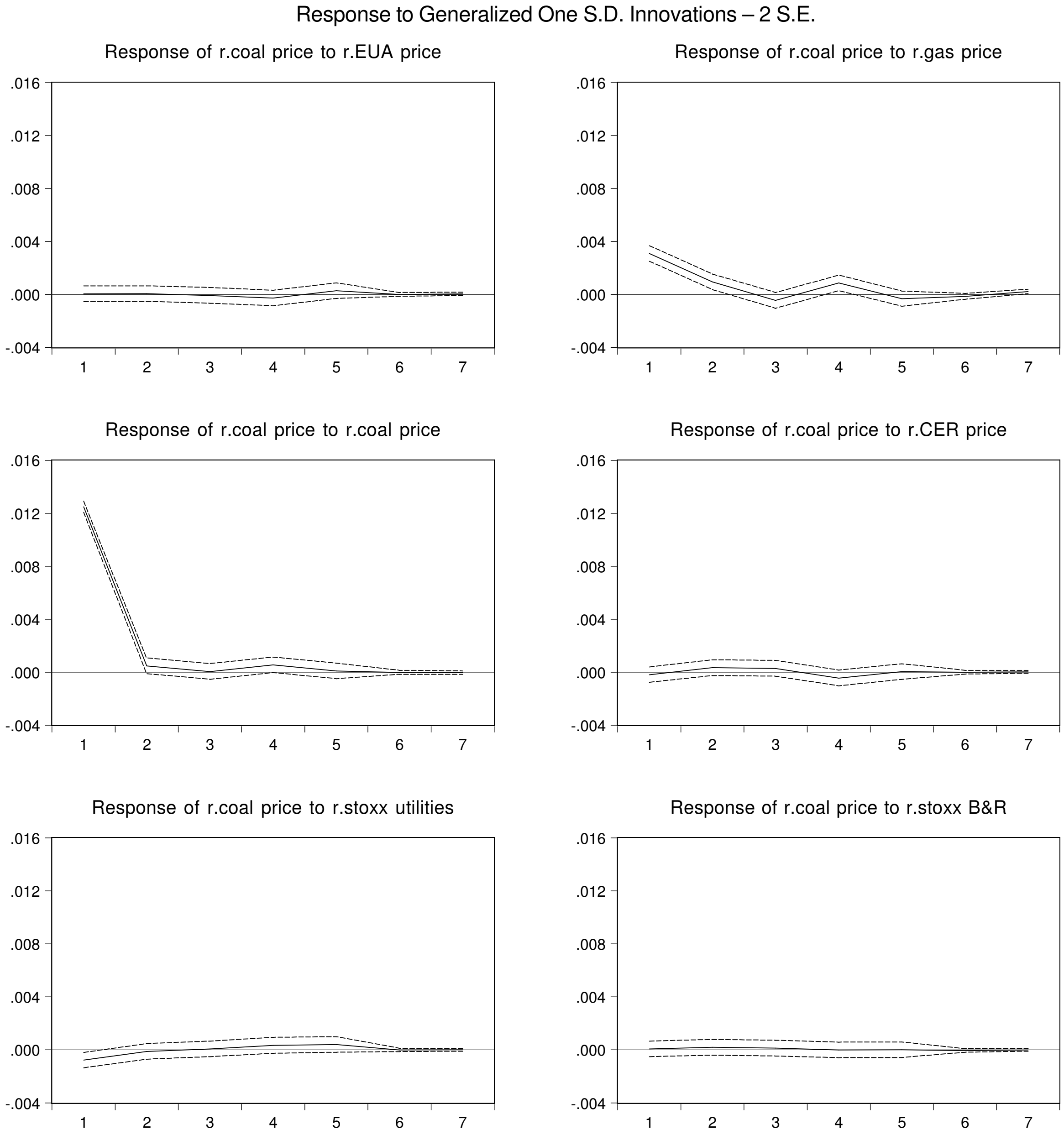


Figure 10: Generalized impulse responses of coal price returns with confidence bands obtained using 5000 Monte Carlo repetitions.

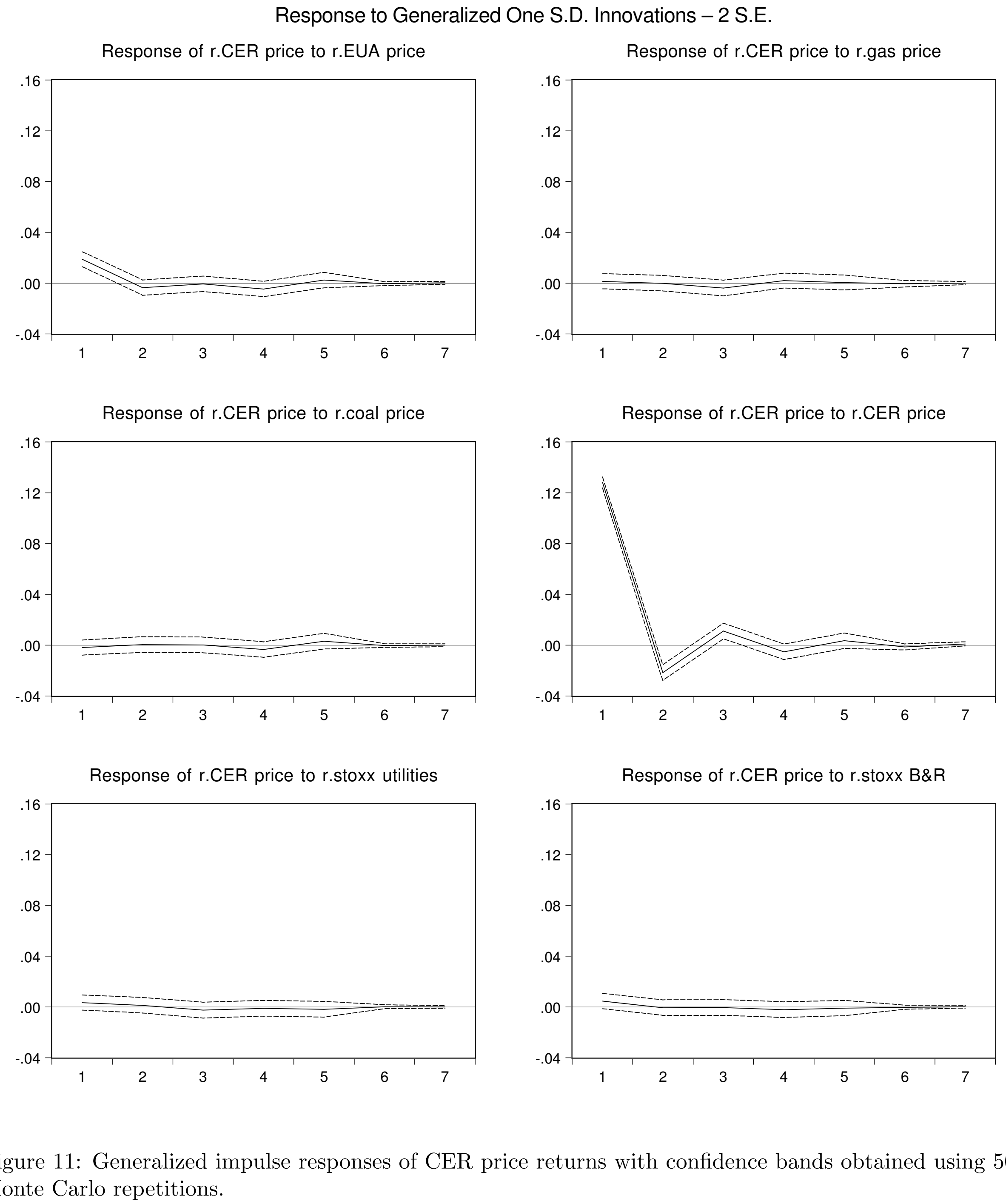


Figure 11: Generalized impulse responses of CER price returns with confidence bands obtained using 5000 Monte Carlo repetitions.

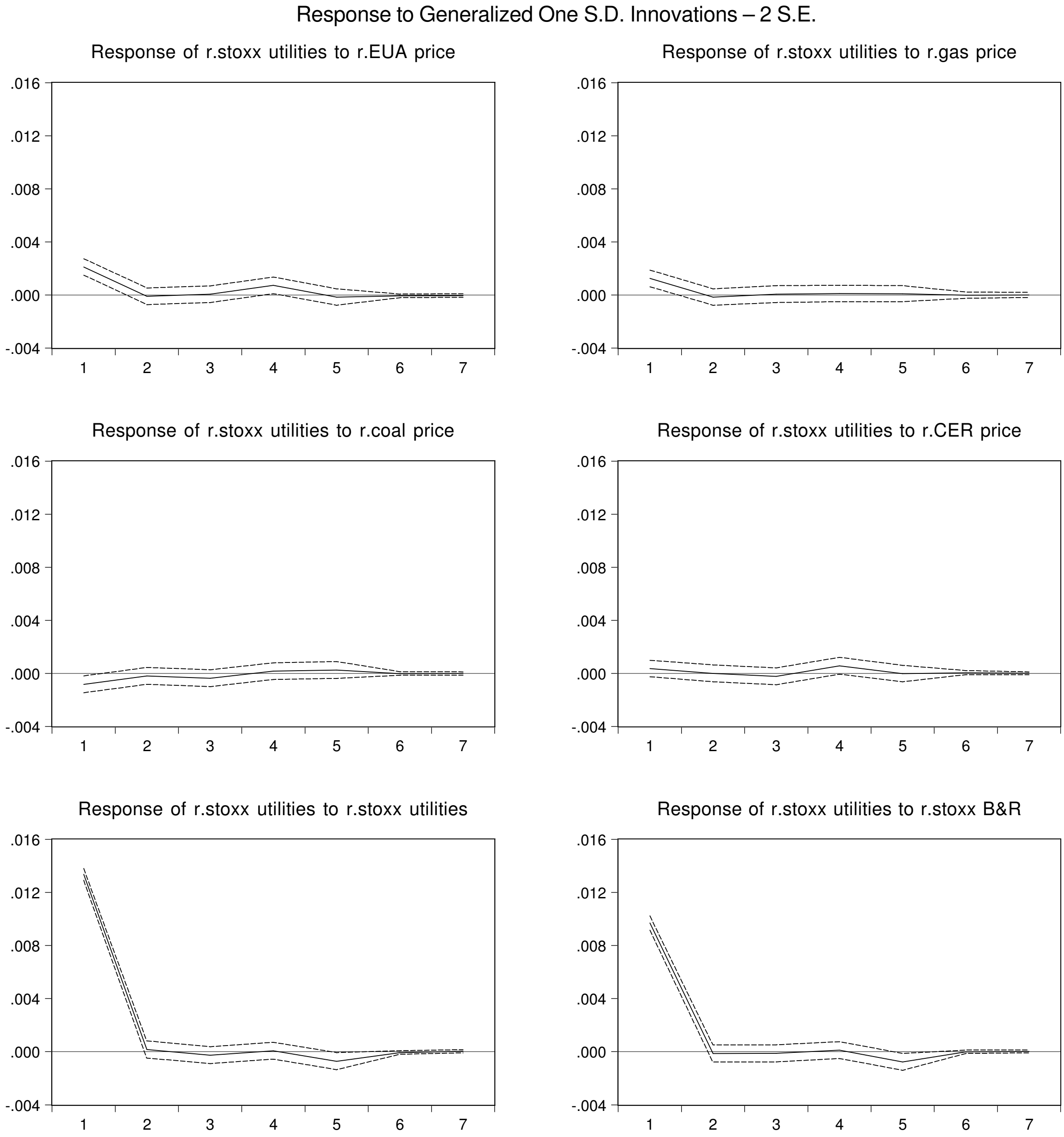


Figure 12: Generalized impulse responses of stoxx utilities returns with confidence bands obtained using 5000 Monte Carlo repetitions.

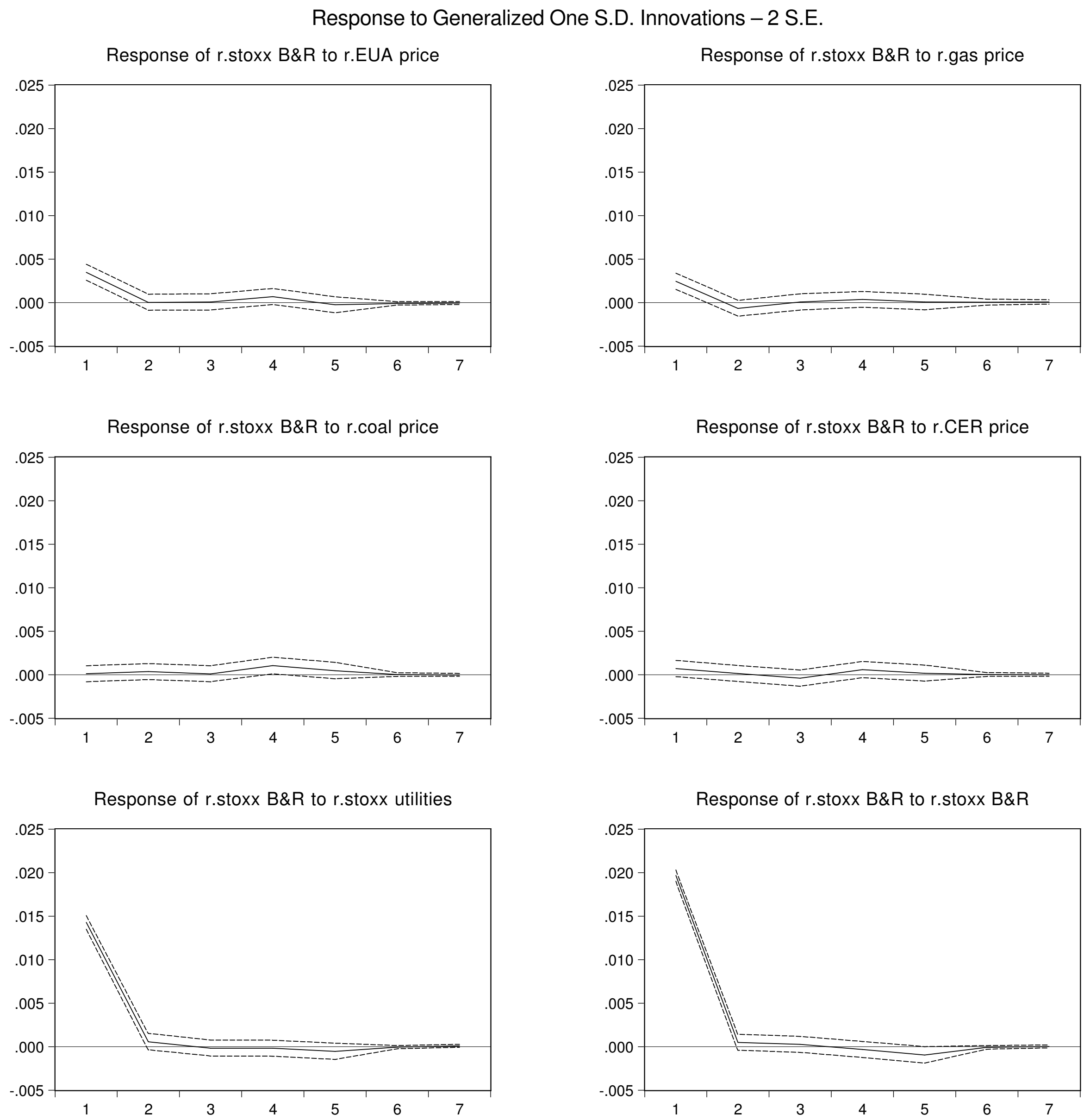


Figure 13: Generalized impulse responses of stoxx B & R returns with confidence bands obtained using 5000 Monte Carlo repetitions.

Table 9: Granger CausalityBlock exogeneity tests based on the VAR model

| Dependent Variable | Explanatory Variables | Chi-sq | df | Prob. |
|---|---|---|---|---|
| r.EUA price | r.Gas price | 3.35 | 4.00 | 0.50 |
| | r.Coal price | 6.71 | 4.00 | 0.15 |
| | r.CER price | 2.81 | 4.00 | 0.59 |
| | r.Stoxx util. | 3.35 | 4.00 | 0.50 |
| | r.Stoxx B&R | 6.71 | 4.00 | 0.15 |
| | All | 28.01 | 20.00 | 0.11 |
| r.Gas price | r.EUA price | 6.35 | 4.00 | 0.17 |
| | r.Coal price | 28.07 | 4.00 | 0.00 |
| | r.CER price | 1.18 | 4.00 | 0.88 |
| | r.Stoxx util. | 1.29 | 4.00 | 0.86 |
| | r.Stoxx B&R | 1.49 | 4.00 | 0.83 |
| | All | 41.82 | 20.00 | 0.00 |
| r.Coal price | r.EUA price | 2.14 | 4.00 | 0.71 |
| | r.Gas price | 22.51 | 4.00 | 0.00 |
| | r.CER price | 4.05 | 4.00 | 0.40 |
| | r.Stoxx util. | 9.38 | 4.00 | 0.05 |
| | r.Stoxx B&R | 6.05 | 4.00 | 0.20 |
| | All | 38.26 | 20.00 | 0.01 |
| r.CER price | r.EUA price | 2.36 | 4.00 | 0.67 |
| | r.Gas price | 2.87 | 4.00 | 0.58 |
| | r.Coal price | 2.20 | 4.00 | 0.70 |
| | r.Stoxx util. | 1.65 | 4.00 | 0.80 |
| | r.Stoxx B&R | 0.87 | 4.00 | 0.93 |
| | All | 9.95 | 20.00 | 0.97 |
| r.Stoxx util. | r.EUA price | 4.21 | 4.00 | 0.38 |
| | r.Gas price | 0.57 | 4.00 | 0.97 |
| | r.Coal price | 2.55 | 4.00 | 0.64 |
| | r.CER price | 2.96 | 4.00 | 0.56 |
| | r.Stoxx B&R | 2.57 | 4.00 | 0.63 |
| | All | 14.50 | 20.00 | 0.80 |
| r.Stoxx B&R | r.EUA price | 2.20 | 4.00 | 0.70 |
| | r.Gas price | 3.54 | 4.00 | 0.47 |
| | r.Coal price | 7.35 | 4.00 | 0.12 |
| | r.CER price | 2.23 | 4.00 | 0.69 |
| | r.Stoxx util. | 2.23 | 4.00 | 0.69 |
| | All | 17.57 | 20.00 | 0.62 |

Table 10: Estimation results when policy dummies are included

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| r.Gas price | 0.190*** | 0.191*** | 0.192*** | 0.044** | 0.043** | 0.044** |
| r.Coal price | −0.096** | −0.086** | −0.092** | 0.031 | 0.030 | 0.031 |
| r.CER price | 0.031*** | 0.026*** | 0.031*** | 0.882*** | 0.882*** | 0.881*** |
| r.Stoxx Util. | 0.040 | 0.049 | 0.041 | 0.028 | 0.027 | 0.026 |
| r.Stoxx B&R | 0.167*** | 0.167*** | 0.167*** | 0.028 | 0.029 | 0.029 |
| I_r.Gas price | | | | 0.259*** | 0.214*** | 0.275*** |
| I_r.Coal price | | | | −0.237*** | −0.189*** | −0.233*** |
| I_r.CER price | | | | −0.863*** | −0.868*** | −0.864*** |
| I_r.Stoxx Util. | | | | 0.104 | 0.119 | 0.093 |
| I_r.Stoxx B&R | | | | 0.021 | 0.023 | 0.034 |
| Backloading | | | | | | |
| Dummy22 | −0.002 | | | 0.019 | | |
| Dummy23 | −0.047 | | | 0.041 | | |
| Dummy25 | 0.047*** | | | 0.048*** | | |
| Dummy26 | −0.068 | | | −0.069 | | |
| Dummy27 | −0.092 | | | −0.089 | | |
| Dummy28 | −0.041 | | | −0.043 | | |
| Dummy30 | −0.432 | | | −0.429 | | |
| Dummy32 | −0.068 | | | −0.068 | | |
| Dummy33 | 0.087 | | | 0.091 | | |
| Dummy34 | −0.007 | | | −0.007 | | |
| Dummy37 | 0.055 | | | 0.054 | | |
| Dummy38 | −0.085*** | | | −0.147*** | | |
| Market Stability Reserve | | | | | | |
| Dummy44 | | 0.042 | | | 0.041 | |
| Dummy45 | | 0.079 | | | 0.079 | |
| Dummy46 | | −0.083 | | | −0.082 | |
| Dummy47 | | −0.028 | | | −0.034 | |
| Dummy48 | | 0.017 | | | 0.016 | |
| Dummy51 | | 0.002 | | | 0.002 | |
| Dummy53 | | −0.006 | | | −0.006 | |
| Long term Policy | | | | | | |
| Dummy03 | | | 0.013 | | | 0.025 |
| Dummy07 | | | 0.020 | | | 0.000 |
| Dummy08 | | | 0.016 | | | 0.006 |
| Dummy09 | | | 0.016 | | | 0.000 |
| Dummy11 | | | −0.012 | | | 0.003 |
| Dummy13 | | | 0.015*** | | | −0.026*** |
| Dummy15 | | | 0.164*** | | | −0.006 |
| Dummy20 | | | −0.015 | | | 0.013 |
| Dummy29 | | | 0.015 | | | −0.017 |
| Dummy35 | | | 0.014 | | | 0.015 |
| Dummy36 | | | 0.039 | | | 0.047 |
| Dummy41 | | | −0.028 | | | −0.022 |
| Dummy43 | | | 0.012 | | | 0.012 |
| Dummy52 | | | 0.006 | | | 0.006 |
| LR test p-value | 0.000 | 0.000 | 0.656 | 0.000 | 0.000 | 0.989 |

*/**/*** attached to coefficients signify that the coefficient is significantly different from zero at the 10%, 5% or 1% level, respectively.

Table 11: Details on the political and regulatory event dummies. The column "No." indicates the number assigned to a certain dummy variable and as used in the regression tables. "Sub", "Back","LT","MSR" and "Other" indicate events that are related to the yearly submission of EUA certificates, backloading, long term persepctives and other political occurrences, respectively.

| No. | Type | Date | Description |
|---|---|---|---|
| 1 | Sub | 01.05.2008 | **EUA Submission 2008** Installations need to submit required quantity of allowances for 2007 by the deadline on May 1st, 2008. |
| 2 | LT | 12.12.2008 | **Compromise 2020 package** The final compromise regarding the energy and climate change package was found by the European Council at its meeting on 11 and 12 December 2008. |
| 3 | LT | 06.04.2009 | **Adoption 2020 package** The Council adopts the climate-energy legislative package containing measures to fight climate change and promote renewable energy. This package is designed to achieve the EU's overall environmental target of a 20 percent reduction in greenhouse gases and a 20 percent share of renewable energy in the EU's total energy consumption by 2020. |
| 4 | Sub | 01.05.2009 | **EUA Submission 2009** Installations need to submit required quantity of allowances for 2008 by the deadline on May 1st, 2009. |
| 5 | Other | 12.03.2010 | **Incorrect CER re-issuance** Bloomberg reports on 12.03.2010, that the Hungarian goverment has re-sold\/re-circulated CER certificates that were handed-in by plant operators already. On 15.03.2010: "Wrong" CERs turned up at the Bluenext exchange in Paris. Also on 16.03.2010: Additional "wrong" CERS were found to be in circulation. Starting on 12.03.2010 price decrease of CERs began finding its low on 16.03.2010. Following the CER low the price spread between EUA Spot und CER Spot jumped to EUR 1,55. On 17.03.2010 CER trading was temporarily stopped. |
| 6 | Sub | 01.05.2010 | **EUA Submission 2010** Installations need to submit required quantity of allowances for 2009 by the deadline on May 1st, 2010. |
| 7 | LT | 26.05.2010 | **Moving beyond 20 percent** Commission outlines the costs and benefits at EU level, as well as the possible policy options, to step up to a 30 percent emission reduction commitment by 2020. |
| 8 | Other | 09.07.2010 | **Cap for 2013** Commission Decision on the Community-wide quantity of allowances to be issued under the EU Emission Trading System for 2013 (first decision of the Commission determining the Cap for 2013). |
| 9 | Other | 22.10.2010 | **Cap for 2013** Commission Decision on adjusting the Union-wide quantity of allowances to be issued under the Union Scheme for 2013 (second decision of the European Commission determining the CAP for 2013). |

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|---|---|---|---|
| 10 | Other | 21.01.2011 | **Partial CER ban** The Member states vote for banning the use of certain HFC 23 and N2O destruction related CERs in the EU ETS. Prospective entry into force May 2013. |
| 11 | LT | 08.03.2011 | **Proposal: Roadmap 2050** Roadmap for moving to a competitive low carbon economy in 2050 proposed by Commission. |
| 12 | Sub | 30.04.2011 | **EUA Submission 2011** Installations need to submit required quantity of allowances for 2009 by the deadline on April 30th, 2010. |
| 13 | LT | 21.06.2011 | **Council support on low-carbon roadmap** European Council emphasizes its support for the Roadmap for moving to a competitive low-carbon economy in 2050 at the Council meeting . |
| 14 | Other | 26.09.2011 | **Decision aviation inclusion** EU Commission decides: from 2012 on aviation is included in the EU ETS. Certificates are issued for free to the aviation sector. |
| 15 | LT | 15.12.2011 | **Support for Roadmap 2050** Support for setting 2050 objectives The Commission presents long-term scenarios for the European energy system in 2050. |
| 16 | Back | 20.12.2011 | **Support for Set-aside** The European Parliament's Environment Committee votes by a margin of one vote in favour of removing 1.4 billion permits and by a wider majority to take away a "significant number" of permits". |
| 17 | LT | 25.01.2012 | **Support for Roadmap 2050** The European Council outlines that the agreement on the low-carbon 2050 strategy and thorough consideration of the forthcoming energy roadmap to 2050 which will provide a detailed analysis on long-term action in the energy sector and other related sectors require urgent progress. |
| 18 | LT | 01.02.2012 | **Moving beyond 20 percent** Commission published a Staff Working Document that analyses the costs and the benefits at the level of Member States of moving beyond its 20% greenhouse gas emission reduction target. This Staff Working Document complements a Communication adopted in May 2010, in which the Commission outlined the costs and benefits at EU level, as well as the possible policy options, to step up to a 30% emission reduction commitment by 2020. |
| 19 | Back | 28.02.2012 | **Support for Set-aside** Industry committee of the European Parliament passes a proposal to let the EU Commission take measures that "may include withholding the necessary amount of allowances". The combined industry and environment voices imply political will for action. |
| 20 | LT | 15.03.2012 | **Adoption roadmap 2050** European Parliament adopts roadmap 2050 for moving to a competitive low carbon economy in 2050. |
| 21 | Sub | 30.04.2012 | **EUA Submission 2012** Installations need to submit required quantity of allowances for 2011 by the deadline of 30 April 2012. |

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| 22 | Other | 14.06.2012 | **Agreement: Energy Efficiency directive** Negotiators from the European Parliament, Commission and Council reach a deal on the Energy Efficiency Directive. But the European Parliament's chief negotiator warns the deal fails to achieve its initial purpose of reaching 20% energy savings by 2020. |
| 23 | Back | 25.07.2012 | **Support: Backloading** Commission formally presents its plans both for the short-term measure of backloading and an outlines a deeper reform, such as permanently removing permits or tightening a cap on how much carbon big emitters can produce. It also says it will accompany this with a simple legal amendment to ensure the legality of backloading. The Commission stresses that agreement is feasible in principle by the end of 2012. |
| 24 | Other | 28.08.2012 | **Support: Linkage with Australian ETS** The intention to link the EU ETS with Australia is made public by the Commission. |
| 25 | Back | 12.11.2012 | **Proposal: Backloading** Commission submits draft amendment to backload 900 million allowances to the years 2019 and 2020. |
| 26 | Back | 24.01.2013 | **Rejection of Backloading** The European Parliament Committee on Industry, Research and Energy rejected the backloading plan, leading the EUA Dec-13 prices to decrease to 3 Euros, a record-low level |
| 27 | Back | 19.02.2013 | **Support: Backloading** Environment Committee supports backloading. |
| 29 | LT | 27.03.2013 | **Green Paper 2030 framework** Commission's Green Paper supports the development of the 2030 framework. |
| 30 | Back | 16.04.2013 | **Rejection: Backloading** First vote by European Parliament on Backloading proposal: Proposal was rejected but not withdrawn. |
| 31 | Sub | 30.04.2013 | **EUA Submission 2013** Installations need to submit required quantity of allowances for 2012 emissions by the deadline of 30 April 2013. |
| 32 | Back | 19.06.2013 | **Support: Backloading** The European Parliaments Envrionmental Committee proposes stricter conditions and advocates an earlier, predictable reintroduction of credits. |
| 33 | Back | 03.07.2013 | **Approval: Backloading** Second positive vote by the EP on the carbon market 'Backloading' proposal. |
| 34 | Back | 16.12.2013 | **Adoption: Backloading** Council adopts backloading through an amendment to the auctioning regulation. |
| 35 | LT | 22.01.2014 | **Proposal: 2030 framework** Commission communicates a policy framework for climate and energy in the period from 2020 to 2030. |
| 36 | LT | 05.02.2014 | **Adoption: 2030 framework** European Parliament votes in favour of a resolution supporting a 30% share of renewables in final energy consumption by 2030 and a 40% energy savings target. The resolution also states a minimum greenhouse gas emissions reduction target of 40% compared to 1990 levels". |

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| 37 | Back | 06.02.2014 | **Support: Fast Backloading** European Parliament approves early implementation of backloading plan. |
| 38 | Back | 25.02.2014 | **Entry into Force: Backloading** |
| 39 | Other | 04.03.2014 | **Non-EU Aviation** Informal agreement between the European Parliament and the European Council to extend exclusion of non-EU aviation until 2016. |
| 40 | Other | 03.04.2014 | **Approval: Aviation Agreement** European parliament approves the informal EUAA agreement. |
| 41 | LT | 21.03.2014 | **Adoption: 2030 framework by Council** The European Council adopted conclusions on the 2030 framework. |
| 42 | Sub | 30.04.2014 | **EUA Submission 2014** Installations need to submit required quantity of allowances for 2013 emissions by the deadline of 30 April 2014. |
| 43 | LT | 24.10.2014 | **Endorsement: 2030 framework** European Council agreed on the 2030 climate and energy framework for the EU. It also adopted conclusions and endorsed targets. |
| 44 | MSR | 17.11.2014 | **MSR** European Parliament Industry Committee discusses official start date of the MSR. |
| 45 | MSR | 13.01.2015 | **Support: MSR** Climate officials from EU member states meet Climate officials of EU member states discuss a proposal by the Latvian presidency to strengthen a planned overhaul of its emissions-trading system by preventing the return to the market of permits delayed at auctions in 2014-2016. |
| 46 | MSR | 22.01.2015 | **Non-binding Rejection: Early MSR** European Parliament industry committee votes against the early start of MSR in 2017 |
| 47 | MSR | 24.02.2015 | **Support: Early MSR** The ENVI committee votes for an early start of the MSR (in the course of 2018) and agrees on introducing the 900 million tons of backloaded volumes into the MSR instead of bringing them back to the market. |
| 48 | MSR | 06.03.2015 | **Discussion: MSR** Discussion paper regarding MSR is published by Latvian presidency on 06.03.2015. The paper includes: MSR start in 2019; but unallocated volumes shall go into the MSR. |
| 49 | Other | 19.03.2015 | **Discussion: Additional German CO2 tax** The German ministry of economics announced that they are considerig levying additional taxes for CO2 emissions on coal power plants should these be older than 20 years. |
| 50 | Sub | 30.04.2015 | **EUA Submission 2015** Installations need to submit required quantity of allowances for 2014 emissions by the deadline of 30 April 2015. |
| 51 | MSR | 05.05.2015 | **Informal Agreement: MSR** Representatives of the EU Council, the EU parliament and the EU Commission agree on MSR and its design. |

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| 52 | LT | 17.05.2015 | **Proposal: Revision of EU ETS** The European Commission presented a legislative proposal to revise the EU emissions trading system for the period after 2020, in line with the 2030 climate and energy policy framework and the Energy Union strategy. Including: Increasing the pace of emissions cuts after 2020; More targeted carbon leakage rules to safeguard the international competitiveness of the sectors most at risk of relocating their production outside the EU; Several support mechanisms to help industry and power sectors meet the innovation and investment challenges of the low-carbon transition. |
| 53 | MSR | 06.10.2015 | **Formal Adoption: MSR** EU Parliament and EU Council approve MSR. |
| 54 | Other | 28.04.2016 | **Court Ruling: CSCF calculation invalid** The European Court of Justice ruled that the European Commission's Cross Sectoral Correction Factor (CSCF) calculations to decide free EUA allocation are invalid, supporting a November opinion by a court advisor that regulators had set too high a ceiling for distribution and thus handed out too many free units. |
| 55 | Sub | 30.04.2016 | **EUA Submission 2016** Installations need to submit required quantity of allowances for 2015 emissions by the deadline of 30 April 2016. |