Modeling and Explaining the Movements in European Union Allowance Prices: A High-Frequency Perspective

Christian Conrad[*], Daniel Rittler[†], Waldemar Rotfuß[‡]

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Abstract

This paper deals with the modeling of the conditional mean and variance of European Union Allowance (EUA) prices. At a daily frequency, a considerable amount of the variation in EUA prices can be explained by changes in fuel prices: increasing coal and oil prices lead to falling demand for CO2 allowances while increasing gas prices imply increasing demand. Most importantly, we analyze the intraday pattern of the volatility of EUA prices which appears to be comparable to the one observed in other equity or exchange rate markets. Moreover, we show that EUA prices react instantaneously to the surprise component in important announcements such as the IFO-index. The strongest reactions are observed in response to the European Community's decisions on the National Allocation Plans (NAPs).

Keywords:CO2 Emission Allowances, Market Efficiency, European Commission, Communication, Expectations

JEL Classification: G13, G14, G15, G17, G19

[*]Christian Conrad, Department of Economics, University of Heidelberg, Grabengasse 14, 69117 Heidelberg, Germany, E-Mail: christian.conrad@awi.uni-heidelberg.de; Phone: +49/6221/54/3173.

[†]Daniel Rittler, Department of Economics, University of Heidelberg, Hauptstrasse 126, 69117 Heidelberg, Germany, E-Mail: daniel.rittler@awi.uni-heidelberg.de; Phone: +49/6221/54/2926.

[‡]Waldemar Rotfuß, ZEW Centre for European Economic Research, Mannheim, P.O. Box 10 34 43, 68034 Mannheim, Germany, E-mail: rotfuss@zew.de; Phone: +49/621/1235/141, fax: +49/621/1235223.

1 Introduction

In January 2005 the European Union Emission Trading Scheme (EU ETS), driven by the Directive 2003/87/EC, formally came into operation. Within the framework of the Kyoto Protocol the European Union has established the EU ETS with the ultimative objective to reduce greenhouse gas emissions. For to fullfill their commitments in a cost efficient way, the European Community and its Member States agreed to construct an efficient European market for emission allowances (EUA), whereas, one EUA warrants the right to emit one tonne of CO_2-equivalent. The market is designed as a cap and trade market. All participating installations, companies operating in the sectors production and processing of steel and iron, minerals, energy or pulp and paper, are grandfathered a certain volume of emission allowances to meet their compliance requirements, according to the cap determinated by the European Commission. The caps the European Commission determinates are fixed in National Alloction Plans (NAP), published by the European Commission and containing the volume of assigned emission allowances as well as the recepting installations. Having been assigned, it is possible to trade emission allowances in many organized market places within the EU ETS.

Beside a wide range of environmental economics related questions, concerning the design of the NAPs (Boeringer et al. (2005)), the allocation procedure (Cramton and Kerr (2002)), or aspects of competitiveness (Oberndorfer and Rennings (2006)), there have been only a few studies concerning price discovery, liquidity or trading process, especially in an intraday perspective.

In one of the first analysis on a daily basis, Mansanet-Bataller et al. (2007) analyze the impact of the market fundamentals oil, natural gas and coal, as well as weather, on the daily EUA log returns in the early stage of the EU ETS, following Christiansen and Arvanitakis (2004) who argue that the way to forecast trends in carbon prices is to assess policy and regulatory issues, market fundamentals and technical analysis. Using an autoregressive distributed lag model neglecting ARCH-effects, Mansanet-Bataller et al. (2007) conclude that the most important factors driving EUA prices are the prices for coal and natural gas. Alberola et al. (2007) extend the framework of Mansanet-Bataller et al. (2007) controlling additionally for sectoral production. In line with Mansanet-Bataller et al. (2007) the authors conclude that the main driving factors are fuel prices. Furthermore they show that sectoral production also affects the EUA price. Mansanet-Bataller and Padro (2007) highlight the impact of regulatory issues, analyzing the effect of NAPs on the carbon prices. Therefore the authors use an event study methodology, whereas they employ dummy variables to represent the event of a NAP announcement, released by the

European Commission, within one day. Mansanet-Bataller and Padro (2007) conclude that the release of NAP announcements has an influence on the EUA price. One of the first paper taking ARCH-effects into account, Benz and Truck (2008) model the EUA daily price dynamics using GARCH-type and Markov-switching models.

As already mentioned, there have been only very few studies addressing the EUA intraday price formation. One of those is Benz and Hengelbrock (2008) who use the Engle and Granger (1987) framework to estimate an error correction model to analyze the joint development of two different exchange-based EUA-price series. Rotfuß (2008) gives an overview of the intraday price behaviour of emmission allowances. To our best knowlege there has been no study to analyze the EUA price series' intraday reaction on the release of new information.

Our contribution to the literature about the EU ETS is twofold. The first extension to the literature lies in the modeling of the EUA price dynamics on a daily basis as well as on an intraday perspective. Taking into account heteroscedasticity and volatility clustering, for modeling the daily log return series we suggest the use of a GARCH-type model, which is in line with the findings of Benz and Truck (2008). On the other hand, due to the periodic pattern and the very slow decay of the sample autocorrelation function of the absolute intraday EUA logreturns we employ a method to filter the periodic pattern and suggest a fracional integrated asymmetric GARCH model (FIAGARCH) for the intraday analysis. The second considerable extension to the existing literature lies in the quantification of the released information, based on an expectation formation model. Contrary to Mansanet-Bataller and Padro (2007), who merely use dummy variables to indicate that the European Commission has released new information, we show the impact on the EUA price of positive and negative deviations of the market participants' expectations from the actually realized volume of allocated EUAs. Furthermore, we analyze the impact of deviations of the market participants' expectations concerning the European industrial production and two German leading indicators. Here, we run our analysis on the basis of daily and intraday data. We think our study should deepen the understanding of how new information is incorporated in the price dynamics in the young market for emission allowances.

The remainder of the paper is organized as follows. Section 2 briefly describes the EU ETS in general and its parts that are most relevant for our analysis in particular. Section 3 presents a model of expectation-formation. In Section 4, we present the employed data and the models used in the empirical analysis. Section 5 summarizes the empirical results of the daily and the intraday analysis, respectively. Finally, Section 6 concludes.

2 The European Emissions Trading Scheme

In 2003, the European Union (EU) established a scheme for greenhouse gas emission allowance trading. The scheme is substantially larger and by far more complex than the pioneering U.S. system for sulfur dioxide. It is based on the Directive 2003/87/EC and formally entered into operation in January 2005; ten years after the US predecessor began operating. The purpose of the European trading scheme is to promote reductions of greenhouse gas emissions in a cost-effective and economically efficient manner. It aims to assist EU Member States (member states in the following) in meeting their commitments under the Kyoto Protocol at minimum costs and has been called the 'New Grand Policy Experiment' of market-based policies in environmental regulation.[1]

The scheme, also known in the literature as the European Union Greenhouse Gas Emissions Trading Scheme, requires selected industrial units to participate in trading of emission allowances. The program covers emissions from four broad sectors: energy, production and processing of ferrous metals, minerals, and other energy-intensive activities (in particular production of pulp and paper). The aviation sector is going to be included in the EU ETS from 2013 onwards. Besides carbon dioxide (CO2) - that accounts for the biggest share of covered gases - five other gases (methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF6)) that are supposed to have an impact on climate change are covered by the scheme. One emission allowance grants the participating installation (or some other holder of it) the right to emit one tonne of carbon dioxide equivalent (tCO2e) during a specified commitment phase.[2]

The EU ETS is divided into three commitment phases (Phase I: 2005-2007, Phase II 2008-2012, Phase III: 2013-2020) and runs on the basis of a 'cap-and-trade' system. The emission cap is defined for each commitment phase by the so called 'National Allocation Plans' that are set up by the member states and approved by the European Commission. We term these various plans as first, second, or third National Allocation Plans (NAPs) according to the commitments phases. The NAPs define both the total quantity of allowances as well as their distribution to participating installations. The allowances are grandfathered or auctioned, whereas grandfathering has been the most common allocation rule in the first two phases. According to the European Commission (European

[1] Kruger, J.A., Pizer, W.A. (2004).

[2] European Parliament and Council (2003).

Parliament and Council (2008)) auctioning should be the basic principle for allocation from 2013 onwards. The allowances are freely tradable after they had been allocated to participating installations.

The participating installations are required to verify their emissions and to surrender the equivalent number of EUAs or other eligible instruments to a competent authority on an annual basis. Installations that have spare number of allowances can sell them on the market. Inversely, any installation that lacks allowances has to purchase them from other installations or market participants. All emissions that are not covered by surrendered EUAs or other eligible instruments are fined with 40 €/tCO2e (in Phase I) or 100 €/tCO2e (in Phase II) and additionally have to be turned in at the next compliance date. The EU ETS is the largest emissions market in the world, but it is relatively small compared to for example energy markets. The annual emission cap equals 2299 million tCO2e in the first commitment period and 2081 million tCO2e in the second. The cap (as an approximation of outstanding EUAs) and the average annual EUA price suggest an annual market value in the first commitment of €30 billion and in the second commitment period of €50 billion, respectively.[3] The European electricity market on the other hand has an estimated annual market value of €224 billion, Farrimond (2008).
Within the EU ETS all participating installations are allowed to use other eligible instruments, the so called Certified Emission Reductions (CERs) or Emission Reductions Units (ERUs), instead of EUAs to meet their compliance requirements (see Directive 2004/101/EC). CERs can be obtained by carrying out emission reduction projects within the framework of the 'Clean Development Mechanism'. ERUs are granted for emission reductions that are achieved under the so called 'Joined Implementation'. Both mechanisms are defined under the Kyoto Protocol and refer largely either to projects that are conducted between developed and developing countries or developed countries only. The expected number of available CERs until 2012 amounts to ca. 1537 million tCO2e (307 million tCO2e per annum according to November 2008 forecast from the UNEP Risoe Centre). Hence, the average CER price (18 €/tCO2e based on the first 11 months of 2008) suggests an annual market value of €5.5 billion.
The usage of alternative credits from the Clean Development Mechanism (CDM) or Joined Implementation (JI) is subject to limits. The limits are defined as a percentage of the member state's allowed cap and sets the maximum number of CERs or ERUs that may be surrendered for compliance by participating installations. The limits are not equal among member states. Some member states are allowed to use up to 20 percent of alternative

[3]The average annual EUA price equals in Phase I 22.3 /tCO2e (2005), 15.1 /tCO2e (2006), 1.3 /tCO2e (2007) and in Phase II 24.0 /tCO2e (based on first eight months of 2008).

instruments (for example Germany, Spain, and Lithuania). All member states in total (excluding Malta) must surrender not more than 278 million CERs/ERUs annually - 13 percent of the EU-wide emission cap. Although the market for other eligible instruments is not bounded to installations from the EU ETS, it is reasonable to assume that most of the annually expected CERs supply of 307 million CERs per annum until 2012 will meet the demand of installations from the EU ETS.

The issuance of EUAs and the conduction of emission reduction projects in exchange for CERs or ERUs are called the primary market for EUAs or other eligible instruments. Trading in all these emission rights constitutes a lively secondary market, which takes place on organised markets and over-the-counter (OTC). The trading in EUAs itself is not specifically regulated or supervised by the EC, although the EC sets the framework, but by each member state and their regulating authorities. The most active trading takes place OTC, with a share of 70 percent of the total daily turnover according to PointCarbon (2008). The remaining 30 percent split up between several exchanges, in most cases energy exchanges that also offer trading in electricity, coal, natural gas, crude oil, and other energy related underlyings. Besides an active EUA spot market there is also a vital derivatives market, where futures, options, and other derivatives on EUAs are traded. The most liquid EUA spot market is BlueNext in Paris, which attracts circa 70 percent of the total daily turnover of the whole organised spot market. The most liquid futures market is ICE Futures in London, which absorbs circa 90 percent of the daily turnover in EUA futures. Trading of other derivative instruments written on EUAs is for the time being negligible. Among other exchanges that offer trading in EUA are EEX in Leipzig, NordPool in Oslo, EXAA in Vienna, CLIMEX in Utrecht, and GME in Rome. All leading exchanges offer trading in other eligible instruments, in particular CERs. However, the activity on the on-exchange CER spot and derivatives markets represents only one quarter of the activity of the on-exchange EUA market (based on the number of traded EUA and CER futures on ICE Futures in 2008). A detailed overview of the activity on the EUA spot and futures market can be found in Benz and Hengelbrock (2008) or Rotfuß(2008).

The trading rules on all organised EUA spot markets are largely identical. Trading consist of continuous trading sessions on working days between 09:00 and 17:00 CET. EXAA is an exemption among these markets with an auction once per working day. The minimum price movement is 1 Euro cent on all spot markets and quoted prices refer to 1 EUA. The number of EUAs per trade is an integer multiple of 1000, 500, or 1 EUAs. The trading rules on all organised EUA derivatives markets allow only for physical delivery and therefore no cash settlement. The minimum price movement is also 1 Euro cent and the underlying unit is 1 EUA. The minimum number of EUAs per trade is identical among all derivatives markets and is an integer multiple of 1000 EUAs. A detailed comparison of all trading rules both of EUA spot and futures markets can be found in Mansanet-Bataller and Padro (2008).

3 Model of Expectation-formation

The assessment of effects of news on EUA prices requires the unexpected component of the considered new information, since only unexpected new information should have an effect on prices. We disregard any price changes that are not a function of the information set of market participants. Therefore, any idle analysis of news effects requires expectations. In the simplest case, expectations can be directly obtained by means of surveys, from which consensus forecasts can be calculated and subsequently used to estimate the parameters of the model. Another possibility is to use a model of expectation-formation, where expectations of market participants are a function of observable variables. The later possibility is pursued in this work.

In search of a suitable candidate among all news that hit the EU ETS our choice primarily falls on announcements about EC's decision on second NAPs. These announcements have been chosen because they constitute a natural experiment. The overall cap in the EU ETS is not set by a single decision, but rather by several decisions that involve each EU member state and the EC. Based on the Directive 2003/87/EC, as amended by Directive 2004/101/EC, each member state designs a NAP, which includes the total number of EUAs (and other eligible instruments) and the rule of allocation. The actual design is based on 12 criteria (11 in Phase I) defined in the Annex III of the EU ETS establishing Directives.[4] Subsequently, the plan is published, undergoes a public consultation, and is notified to the EC and other member states. Within 3 months of notification, the EC accepts or rejects the plan, or any aspect thereof, on the basis of mentioned criteria. The public is informed by the EC via a press statement about the decision. In case of any rejections, the EC has to provide reasons and proposals for amendments and the member state is allowed to resubmit an amended NAP. The process of allocation of EUAs to participating installation by the member states is allowed only if the EC accepts all amendments; hence, the last rule leaves the final decision on NAPs to the EC or in case of dispute to the European Court of Justice. All in all, there are at least 27 decisions of the EC on NAPs and the whole approving process can be considered as transparent. It is a natural experiment, since there are several observations (decisions of the EC) on the

[4]The criteria include, for example, obligations to allocate an amount of allowances that is consistent with the Kyoto Protocol and the environmental commitments of the European Union.

same subject, namely the establishment of the overall cap in the EU ETS.
Having found the suitable candidate, the remaining difficulty in our analysis arises from finding the right formula for expectation-formation of market participants. In general, expectation-formation can take different forms. We let the expectations be a function of the total number of EUAs that have been approved in the first NAPs.[5] Of course, this procedure assumes that market participants disregard what ever member states have notified to the EC in their NAPs for the second commitment period. But after a thorough investigation of the EU ETS framework, studying related press releases, and interviewing market participants, it seems to be a widely accepted feature of the EU ETS to treat first NAPs as a point of reference. Finally, the tough-sounding statements of the EC that it will allow only tight caps (see Barroso 2006a) prepared the market for a cut of NAPs. We assume that the market participants in the EU ETS build up their expectations in regards to the EC's decision on second NAPs according to the following formula:

$$E[y^i_{t,k}|F_{t,k-1}] = \begin{cases} (1-cut)\cdot X^i, & \text{if } y^{i,submitted} > (1-cut)\cdot X^i \\ y^{i,submitted}, & \text{if } y^{i,submitted} < (1-cut)\cdot X^i \end{cases}$$

$E[y^i_{t,k}|F_{t,k-1}]$ is the conditional expectation of market participants on the EC's decision on the total number of EUAs in member state's $i, i = 1, ..., N$ second NAP, whereas the EC's decision is released on day $t, t = 1, ..., T$ in the h minute interval $k, k = 1, ..., K(h)$. N refers to the number of considered announcements - to be precise, the number of member states. X^i is the total number of EUAs in members state's i first NAP that is known to all market participants. *cut* is a constant between 0 and 1 that defines the percentage reduction of the total number of EUAs compared to the first commitment period. It can be considered as a lump cut of first NAPs. $y^{i,submitted}$ is member state i's total number of EUAs in the second NAP that is notified to the EC and known to the public as well. $F_{t,k-1}$ is the information set of all market participants shortly before the release of the considered announcement. The conditional expectation equals the submitted number of EUAs, if cut leads to a greater expected number of EUAs than notified to the EC (our escape clause).
Our formulation of expectations states that the lump cut is identical among all market participants and for all member states, implicitly assuming that *cut* is a constant with a real value between 0 and 1. Of course, these assumptions are not true for every market

[5]We tried another possibility of expectation formations where the point of reference equals the submitted number of EUAs for the second commitment period or total realised emissions of participating institution in 2005. However, the results show that both alternatives do not lead to better explanations of EUA price reactions.

participant. But for convenience it is justified to set *cut* to a constant and assume that it is an average of individual lump cuts of all market participants. This means also that the calculated conditional expectation $E[y^i_{t,k}|F_{t,k-1}]$ is an average of all individual conditional expectations of market participants. If we were able to observe the expectations of all market participants, we could estimate *cut*. This train of thoughts is supported by a publicly cited analyst, who expected a 10 per cent cut of second NAPs (see PointCarbon 2006b). The estimate of the cited analysts can be regarded as a random draw from a distribution of individual lump cuts of all market participants. The intuition for treating *cut* equal for all member states is different, but rather simple. Due to the over-allocation in the first commitment period, every member state has to contribute the same percentage to the reduction of the total number of EUAs in the second commitment period to achieve a functioning market. In our view this is the only rule that can be termed as 'fair' as stated by José Manuel Barroso before the first official release of EC's decision on second NAPs (see Barroso 2006b).

Although it is possible to draw some conclusions about the properties of *cut*, there are to our best knowledge no official statements of the EC or its members that support a target value. Therefore, we set the value of *cut* ad hoc to 7.5 per cent and back up our choice by providing results for a range of values between 0 and 10 per cent and some arguments given in Section 4. Unless not stated otherwise, the expectations of market participants refer in the following always to a lump cut of 10 per cent.

4 Data and Methodology

4.1 Data

4.1.1 Price Data

As already mentioned, the European market for emission allowances is both, an over-the-counter and an exchange-based market. To analyze intraday price formation we use ICE ECX CFI futures transaction data. Our original sample consists of irregularly spaced tick-by-tick quotes of ICE ECX CFI futures with several maturities traded as well over-the-counter as traded exchange-based. In order to have a sufficient number of observations, we focus on the futures with maturity in December 2008 because of the largest trading volume, whereas we only regard exchange-based transactions. Considering the low data density in the early stage of emissions trading in 2005 and 2006, we decided to run our analysis from 01/11/2006 to 01/09/2008. As a whole we consider 466 trading days. Contrary to Benz and Klar (2008) who only account for transactions within the time-frame from 08:00 to 15:30 we use the data right from the start at 07:00 to the end of exchange-based trade at 17:00. To discover intraday price formation we transform the original data to equidistant intraday prices at frequencies $h = 10, 30$ and 60 minutes. Taking the immediately preceding and following quote at the end of each h-minute interval we compute the mean to get the price at the h-minute mark. If the observed time stamp of the transaction equals the h-minute mark we use the corresponding price as the equidistant intraday price at frequency h. If there is no transaction at the first h-minute mark at 07:00 the first intraday price equals the last price of the preceding trading day. In general to avoid overnight effects we do not take the mean of transaction prices of two different days. The price of the last h-minute mark of the trading day at 17:00 equals the price of the last observed transaction. Taking the price series at h-minute frequency we construct the h-minute return

$$R_{t,k}(h) = (log(P_{t,k}(h)) - log(P_{t,k}(h))) \cdot 100, \quad t = 1, ..., T \quad \text{and} \quad k = 1, ..., K(h)$$

as change in the h-minute log prices, where T is the number of days in our sample, $K(h)$ is the number of h-minute intervals per day and $P_{t,k}(h)$ is the intraday price at frequency h of the k-th h-minute interval of the t-th day. The summary statistics of the return series at frequencies $h = 10, 30, 60$, as reported in Table 1, show that the means of the h-minute returns are close to zero. Due to excess kurtosis and skewness different from zero, the h-minute return distributions are clearly non Gaussian which is also confirmed by the Jarque-Bera statistic.

Table 1: Descriptive Statistics for high-frequency data

Series	# obs.	Mean	Skewness	Kurtosis	Ljung-Box(20)	Jarque-Bera
$R(daily)$	465	0.0988	-.4607	5.4687	21.27 [0.323]	37.41 [0,000]
$R(60)$	4659	0.0095	-0.1852	14.9623	> 1000 [0.000]	72.01 [0,000]
$R(30)$	9319	0.0051	0.2107	16.2884	> 1000 [0.000]	61.73 [0,000]
$R(10)$	27959	0.0017	0.3148	33.6230	> 1000 [0.000]	81.22 [0,000]

Notes: p-values in brackets.

The weak serial correlation for low lags, as often reported for high-frequency data, also exists in the EUA log return series at each of the analyzed frequencies.[6] A contrary

[6]See e.g. Conrad and Lamla (2007) who analyzed high-frequency returns of the EUR-US$ exchange

picture is observed for the squared and absolute log return series. So, the serial correlation for low lags and for high lags as well that is usual to observe for high-frequency data also exists in the EUA market and is shown in Figure 1.

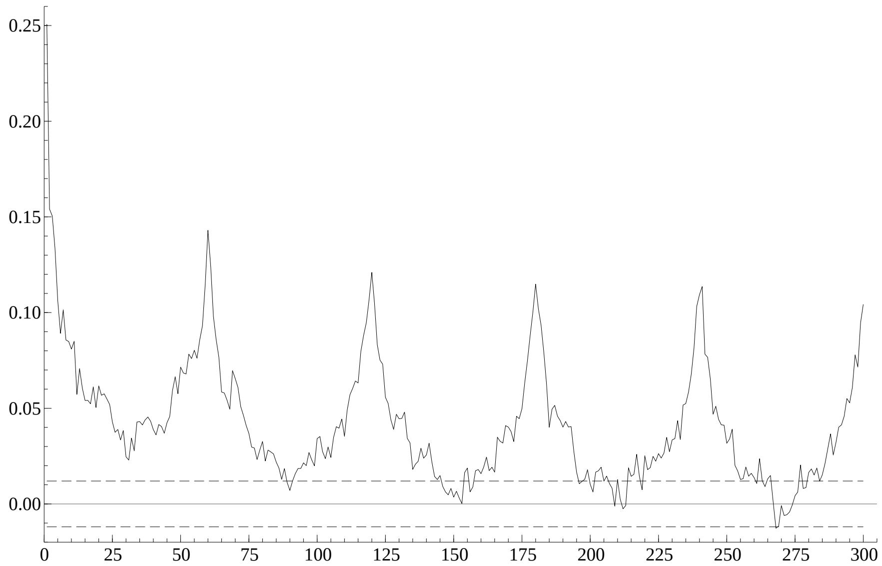

Figure 1: Sample autocorrelation function of ten-minute absolute C02 returns for five consecutive trading days. Dashed lines are 95% confidence bands.

Figure 1 depicts the sample autocorrelation function of ten minute absolute carbon returns for five consecutive trading days and reveals the intraday periodic pattern. Due to the frequency $h = 10$, we have 60 10-minute intervals per day. Figure 1 points out a relative fast decay of the sample autocorrelation function within the first half of the trading day. Having past half of the trading day the serial correlation starts to increase again to find a local peak exactly at the same time of the consecutive day (lag 60) to decay again till the half of the consecutive day. Beginning to increase from that point the autocorrelation function reaches a second local peak exactly at the same time of the consecutive day (lag 120) and so forth, whereas the amplitute of the local peaks shrincs slowly.

In the following, we focus our analysis on the the the absolute log returns' intraday formation in more detail. Therefore, we employ the function

$$f_k(h) = \frac{1}{T} \sum_{t=1}^{T} |R_{t,k}(h)|$$

rate.

to filter the intraday perodic pattern from the equidistant series at frequency h. That means we compute the average absolute log return of each h-minute interval $k = 1, ..., K(h)$ over all trading days $t = 1, ..., T$. In Figure 2 we show the intraday seasonality for $h = 10$.

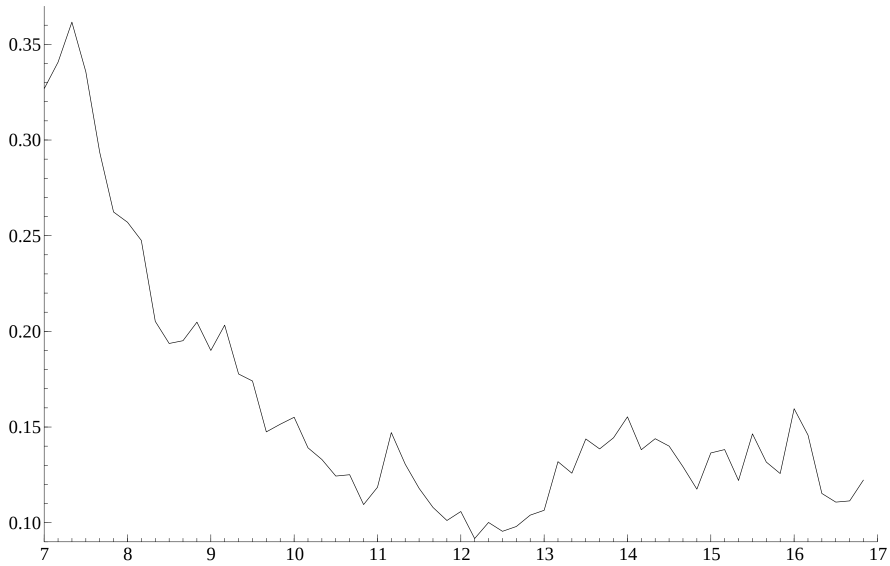

Figure 2: Average absolute ten-minute CO2 returns for each ten-minute interval during a trading day.

With the market opening, the average absolute return starts at a relatively high level and even increases within the first few intervals to reach the all-day high at 07:30. From there on, the average absolute return starts to decrease strongly to find its all-day low within the European lunch time from 12:10 to 13:00. Beginning at 13:00 the average absolute return starts to increase again to reach a local peak at the late afternoon and falls nearly to its all-day low at the end of the trading day.

Finally to extract the seasonality from the log return series, we compute the filtered log return series

$$\tilde{R}_{t,k}(h) = \frac{R_{t,k}(h)}{f_k(h)}.$$

Having filtered the intraday log return series accordingly to the described procedure, we compute the sample autocorrelation function of the filtered ten-minute absolute carbon returns for five consecutive trading days, pictured in Figure 3.

Figure 3 points out that filtering the intraday periodic pattern was successful, because the periodicity is not observable anymore. However, it should be mentioned that the sample autocorrelation functions slow decay is a first sign that the use of an FIGARCH-type model is likely to outperform a commonly used GARCH-type model.

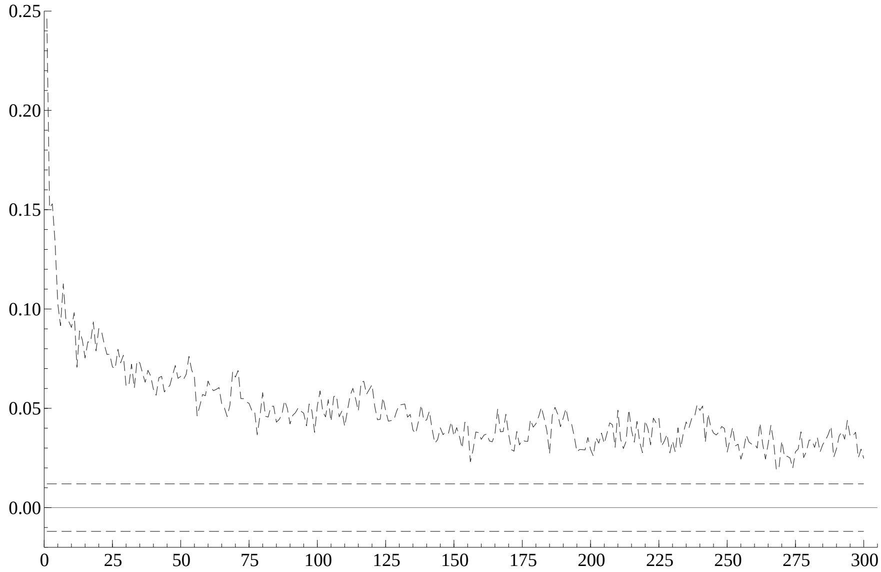

Figure 3: Sample autocorrelation function of *filtered* ten-minute absolute C02 returns for five consecutive trading days. Dashed lines are 95% confidence bands.

Furthermore, following Anderson et al. (2003) and Barndorff-Nielsen and Shephard (2002), we use the squared log returns to construct the realized volatility

$$RV_t(h) = \sum_{k=1}^{K(h)} R_{t,k}^2(h)$$

for trading day $t = 1, ..., T$ at frequency h as a sophisticated measure of volatility. That means the realized volatility of trading day $t = 1, ..., T$ equals the sum of squared high-frequency intraday log returns. Under general conditions realized volatility converges to the latent and unobservable return volatility over the corresponding period of time in probability for $h \to 0$. Furthermore, daily realized volatility calculated by high-frequency data represents a more precise measure of daily integrated volatility than daily squared or absolute returns.

4.1.2 Announcement Data

In several cases the EC approved the NAPs conditionally on changes to the total number of emission allowances. In some cases, the EC has proposed informal emission caps for few member states that have been accepted without any complains and some member states withdrew their proposed NAP shortly before the decision. So given the described procedure of the overall cap, there were in total 27 (conditional) NAP approvals. There were also 6 decisions on amendments and 3 information leakages - publications of the EC's decisions before the release of the actual decision (happened in case of Germany, Belgium, and Ireland) - that we exclude from the analyses because of reasons given below. Our data on NAPs announcements consists therefore of 27 announcements that took place between 20/11/2006 and 26/10/2007. The release of the EC's decision was sporadic, but scheduled. The release time of the decisions equals in our setting the time it was delivered to the public via Point Carbon, a known news agency in the carbon market. Other data, especially the number of approved EUAs in the first and second NAPs, were gathered from the EC's website.

Our model of expectation-formation depends heavily on $F_{t,k-1}$. In a perfect experiment we would not let $F_{t,k-1}$ to change between each decision of the EC. Unlike to perfect experiments, we have to deal with information that leaks out to the market. In particular, there were to our knowledge three information leakages in the considered period, of which two are relevant for our analyses.[7] In case of Germany, an internal EC request to cut the submitted number of Germany's EUAs hit uncontrolled the market. And in case of Belgium, the official EC decision leaked out to the market one day before the official release. We account for these information leakages by replacing the calculated expectations for Germany and Belgium with the leaked out values. We do not consider the surprises from information leakages itself, because of two reasons: the accurate timestamp of the leak out is not known, even though it could be reasonable to set it at the market opening, and the reaction of EUA prices could be different in case of information leakages compared to schedules announcements. The third information leakage occurred in case of Ireland, where the EC's decision on the amended NAP reached the market before the official release. Since we discard the effects of the EC's decision on amended NAP from our analyses, it is not necessary to control for the leak out in case of Ireland.

We define the unexpected part of the announcements as $S^i_{t,k} = y^i_{t,k} - E[y^i_{t,k}|F_{t,k-1}]$, with $y^i_{t,k}$ as the total number of EUAs in the second NAP of member state i that have been accepted by the EC and published on day t in the h-minute interval k. Negative $S^i_{t,k}$ imply an unexpected cut or under-allocation with emission allowances (a reduction compared to Phase I) and positive, consequently, an unexpected over-allocation with EUAs.

Based on our model of expectation-formation, market participants expect on average an allocation of 78 Mio EUAs per NAP, with a standard deviation around 103 Mio. The smallest number of EUAs is expected for Malta (2.49 Mio), and the highest for Germany (465 Mio). In a next step we standardize the surprise by dividing the surprise by the

[7] There were also information leakages before our considered period, see for example PointCarbon (2006).

sample standard deviation σ, that means

$$\tilde{S}_i = \frac{y^i_{t,k} - E[y^i_{t,k}|F_{t,k-1}]}{\sigma}.$$

Finally, employing a standard technique in the literature (Gravelle and Moessner (2001)), we test for unbiasedness of the announcements. The test whether the expectations of the announcements are unbiased are based on the simple regression equation

$$y^i_{t,k} = \alpha + \beta \cdot E[y^i_{t,k}|F_{t,k-1}] + u^i$$

whereas the unbiasedness test is a Wald test of the joint hypothesis $H_0 : \alpha = 0 \cap \beta = 1$. The conditonal expectation $E[y^i_{t,k}|F_{t,k-1}]$ is defined under the expectaion formation model in Section 3. In Table 2 we show the test results for $cut \in \{5\%, 7.5\%, 10\%\}$. We find that for $cut \in \{7.5\%, 10\%\}$ the survey expectations are of good quality as they prove to be generally unbiased.

Table 2: Test of Unbiasedness

	α	β	R^2	Wald-Test	# obs
NAP($cut = 0.1$)	1.075 (0.868)	0.989 (0.194)	0.996	0.79 [0.467]	27
NAP($cut = 0.075$)	0.434 (0.643)	0.982 (0.016)	0.997	0.70 [0.506]	27
NAP($cut = 0.05$)	−0.118 (0.547)	0.976 (0.014)	0.997	1.95 [0.163]	27
ifo-Index	−8.814 (11.365)	1.082 (0.108)	0.876	0.45 [0.647]	20
ZEW-Index	−2.222 (1.764)	0.977 (0.057)	0.938	0.82 [0.457]	20
EUIP	0.067 (0.109)	0.859 (0.067)	0.578	4.42 [0.027]	20

Notes: p-values in brackets, robust standard errors in paretheses.

Additional to the NAP announcement data, we accounted for further announcements, containing surprises of the European industrial production, the ZEW-index, the ifo-business climate index on the one hand and carbon market related information on the other hand. To only take new information of the additional announcements into account we construct the surprise for the variables j, $j \in$ {ifo-Index, ZEW-Index, European industrial production} within the time interval k at day t by deducting the expectation of the announcement $E^j_{t,k-1}$ from the actual announcement value of the variable $A^j_{t,k}$ as we did before with the NAP announcement data. It should be stressed here that the expectation is built regarding the information set available right before the release of the announcement at day t within the k-th h-minute interval. Since the unit of measurement differs across variables, we will use the standardised surprise $\tilde{S}^j_{t,k} = (A^j_{t,k} - E^j_{t,k-1})/\sigma^j$ in the econometric analysis below. Again we prove unbiasedness of the surprises applying the Wald test proposed above. Since we do not have any expectations of CDMs and CERs we decided to take the actual numbers published on the Point Carbon web site.

4.1.3 Anticipated Carbon Price Reactions

We split our analysis into two parts, whereas in the first part we analyze carbon price reactions on the release of new market relevant information on a daily basis while we also incorporate coal, oil and natural gas. The coal price we control for, is given by the Global Insight Coal Index Basis 6000 measured in US$ per Gj. For the oil price we take the London Brent Crude Oil Index measured in US$ per BBL and for the gas price we regard the Natural Gas-Henry Hub US$ per MMBTU. We convert all price series using the US$/€ exchange rate provided by the European Central Bank. Using the converted series we construct the fuels' daily log return series, which are taken for the daily analysis. In the second part of our empirical work we analyze the effects of the release of new information on an intraday basis.

The European carbon market is designed as a cap and trade market. By approving the NAPs set up by the member states governments, the European Commission determines the cap and, hence, the most important EUA price determinant. Setting tight caps implicates a short supply of EUAs and consequently a high carbon price by trend. On the other hand setting broad caps implicates a higher number of EUAs available in the carbon market leading to a low carbon price by trend. Since carbon prices reflect the market participants' expectations of the caps the European Commission will approve, only the surprise component in the approval will affect carbon prices. Therefore we anticipate that a positive surprise and, consequently, an unexpected over-allocation with emission allowances, should lead to a EUA price decrease. Having a negative surprise and, hence, an under-allocation with EUAs we anticipate a positive EUA price reaction.

Due to the framework of the Clean Development Mechanism and the associated possibility to use other eligible instruments instead of EUAs to meet participating installations' compliance requirements, as describe above, we anticipate that the total number of approved CDM projects should be a determinant of the carbon price. We anticipate that an extension of approved CDM projects implicates a negative carbon price reaction caused by additional CERs available, leading to an additional allocation, that can be used to meet compliance requirements or to be traded in the carbon market, respectively.

As often stated in the literature (see i.e. Mansanet-Bataller and Pardo (2007)) some of the most relevant EUA price driving factors are relative fuel prices, especially those for oil, coal and natural gas, due to the ability of power generators to switch between fuel inputs in the power generation. In this connection, it sould be kept in mind that the power generating sector attracts the by far largest quantity of grandfathered EUAs. Generators producing power with multi-fire units, that means installations with the opportunity to use two or more different fuels in the production process, are able to subsitute the relativly expensive fuel within one single day, provided that an alternative fuel is available immideatly and no major modifications of the unit are needed. Hence, rational generators using multi-fire units will exploit short-term price differentials between fuel prices. The reason for the fuel switch affecting the carbon price lies in different carbon intensities of different fuels leading to different carbon emissions to achieve a certain level of output. The most carbon intensive fuel is coal with a carbon emission factor of 94.7 followed by oil (73.4) and natural gas (56.2); with other words, producing power by coal is nearly twice as carbon intensive as producing power by gas.
Infront of that background, we anticipate a positive gas price movement results in substituting gas by coal or oil in the power generating sector leading to higher carbon emissions, due to the higher carbon emission factors, and finally to an increased EUA demand implicating a positive EUA price movement. Else, a positve coal price movement results in substituting coal by gas or oil leading to lower carbon emissions, due to the lower carbon emission factors, and finally to decreased EUA demand implicating a negative EUA price movement. Positive oil price movements can result in substituting oil by gas or coal leading to lower or higher carbon emissions. That means either to positive or negative EUA price movemets.
In the intraday analysis we do not account for fuel prices due to two reasons. On the one hand, power generators are not able to switch from one fuel to another within only few minutes. On the other highly informative high frequency data on the fuel price series have not been available for this paper.

Another EUA price driving factor stated in the literature is industrial growth. The rationale behind that is that with an increased industrial production participating installations will rise carbon emissions due to the expansion of their production. Furthermore the expansion of the production will imply an increased consumption of electricity. Sticking to the mentioned reasoning we anticipate a positive surprise in the industrial production leading to an increased EUA demand implicating a positive EUA price movement.

Two further variables that have not been accounted for in the literature yet, are the leading indicators ZEW-index and ifo-business-climate-index. Being a measure of producer confidence we anticipate positive surprises in the indicators leading to positive EUA price reactions, since we interpret positive surprises as a sign of an unexpected positive economic development leading to higher industrial production and finally to higher demand for emission allowances.

4.2 Methodology

We assume that R_n can be described by an autoregressive distributed lag model, where the explanatory variables are given by the standardized surprise variables:

$$R_n = \mu + \sum_{j=1}^{p} \phi_j R_{n-j} + \sum_{i=1}^{I} \delta_i \tilde{S}_{i,n} + \varepsilon_n \tag{1}$$

with $\varepsilon_n = \sqrt{h_n Z_n}$ and $Z_n \overset{iid}{\sim} \mathcal{N}(0,1)$. The conditional variance h_n is either specified as a asymmetric GARCH (AGARCH) model

$$h_n = \omega + (\alpha + \gamma \mathbf{I}_{\varepsilon<0})\varepsilon_{n-1}^2 + \beta h_{n-1} \tag{2}$$

or a fractionally integrated AGARCH (FIAGARCH)

$$(1-\beta L)h_n = \omega + \big((1-\beta L) - (1-L)^d(1-\phi L)\big)\,(|\varepsilon_n| + \gamma\varepsilon_n)^2. \tag{3}$$

The FIAGARCH model is an extension of the FIGARCH proposed by Baillie et al. (1996) which allows for asymmetric feedback of positive and negative shocks to the conditional variance. While the GARCH model implies that shocks to the conditional variance dissipate at an exponential rate, it is the particular feature of the FIGARCH that the impact of shocks decays at a slow hyperbolic rate. The decay behavior of the autocorrelation function of the absolute filtered return series investigated in the last section suggests that the FIGARCH may be better suited than the GARCH for modeling the intraday EUA price movements.

5 Empirical Results

Table 3 presents the results for the daily data. The initial specification included the variables natural gas, oil, coal and the standardized announcement data. Using a general to specific approach all insignificant variables were deleted and Table 3 contains the final specifications.

As mentioned in Section 4, prices for oil, natural gas and coal will have an impact on the price of carbon because of the ability of power generators to switch between their fuel inputs. The coefficient estimate on gas is 0.07 and highly significant, suggesting that higher gas prices lead to a switch to the more carbon intensive coal and, hence, the positive impact on carbon returns.[8] To the contrary, the coefficient estimate on coal is negative and significant at the 10% level, implying that higher coal prices lead to a switch to the less carbon intensive gas and thereby to lower carbon prices. Finally, the coefficient on oil is again negative and highly significant. This result suggests that oil is substituted mainly by the less carbon intensive gas and is in line with the findings in Soderholm (2001) who reports a significant short-run interfuel substitution, especially between oil and gas.

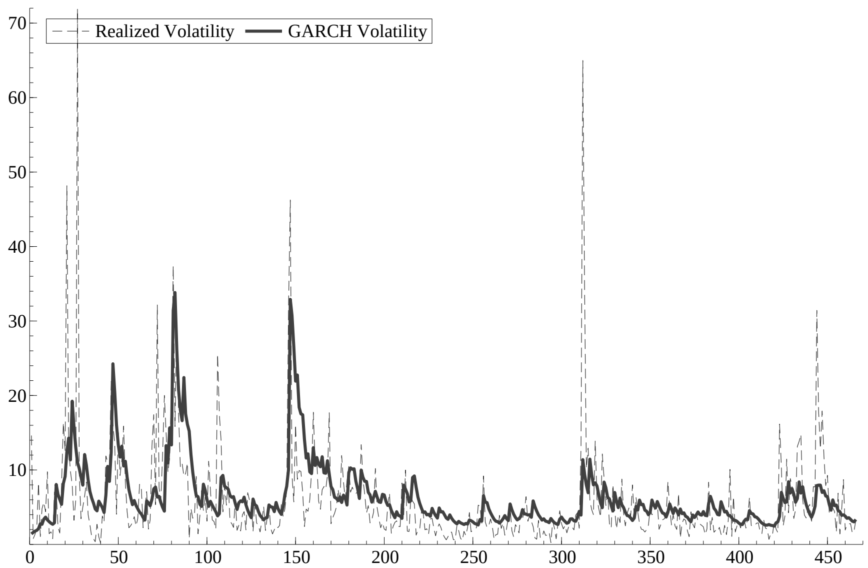

Figure 4: Realized volatility versus estimated GARCH volatility.

Only the announcements on European area industry production and the national allocation plans led to significant price reactions. As expected, a positive surprise in industrial production leads to higher carbon prices by signalling an increasing demand for carbon allowances.

In order to control for the existence of a risk-return relation, we also included the realized volatility (as constructed from the ten-minute returns) in the mean equation. The parameter estimate points to a negative and significant risk-return relation which

[8]Following Lowrey (2006) "if the price of gas increases relatively to the price of coal, then the cost of cutting emissions by switching from gas to coal increases and - other things being equal - the demand for coal will increase. Therefore, the demand for carbon allowances to cover that generation will also rise, leading to a resultant increase in emission allowance prices".

Table 3: Parameter Estimates for Daily Data

	R_t	V_t
	Mean Equation	
μ	$0.452^{\star\star\star}$ (0.118)	-0.126 (0.123)
GAS	$0.070^{\star\star\star}$ (0.027)	$0.015^{\star\star\star}$ (0.006)
$COAL$	$-0.034^{\star}$ (0.020)	-0.010 (0.013)
OIL	$-0.211^{\star\star\star}$ (0.074)	$-0.024^{\star}$ (0.014)
$EUIP$	$0.087^{\star}$ (0.047)	0.013 (0.030)
NAP	$-0.238^{\star}$ (0.124)	0.005 (0.010)
RV_{10}	$-0.059^{\star\star}$ (0.022)	$0.025^{\star\star\star}$ (0.002)
	Variance Equation	
ω	$0.519^{\star\star}$ (0.238)	$0.007^{\star\star}$ (0.003)
α	$0.164^{\star\star}$ (0.069)	$0.064^{\star\star}$ (0.026)
β	$0.757^{\star\star\star}$ (0.081)	$0.906^{\star\star\star}$ (0.035)
AIC	4.57	1.25
SIC	4.66	1.39
$Q(20)$	17.48 [0.62]	16.47 [0.35]
$Q^2(20)$	16.20 [0.70]	7.32 [0.95]

Notes: p-values in brackets, robust standard errors in paretheses.

can be interpreted as evidence for the so-called volatility feedback effect (see Campbell and Hentschel, 1992): rising volatility leads to an increase in the discount rate and, consequently, in a drop of the stock price. The three GARCH parameters are highly significant and imply that the squared innovations follow a covariance stationary process. Finally, the Ljung-Box statistics indicate that there is no remaining serial correlation in the standardized and squared standardized residuals. The volume can be mainly explained by the gas and oil price changes and the realized volatility, whereby in the first two cases the estimated coefficients have the same signs as before. Higher realized volatility leads to an increase of the traded volume. Figure 4 provides a comparison of the GARCH estimated daily volatilities $\hat{h}_n$ with the realized volatility $RV(10)$. The visual impression of an extremely good fit is confirmed by the Mincer-Zarnowitz regression of $RV(10)$ on the estimated conditional variances:

$$RV(10) = \underset{(0.53)}{0.92} + \underset{(0.10)}{0.78}\hat{h}_n \qquad \text{with} \quad R^2 = 0.24 \tag{4}$$

In a first step, we estimated the same AGARCH models for the intraday data. However, the conditional variance of the intraday returns appears to be much more persistent, which is evident from the estimated β coefficients greater than 0.9 in combination with very low α coefficients. The Ljung-Box statistics reject the null hypothesis of uncorrelated squared standardized residuals at the 1% percent level. Given that evidence, we estimated the FIAGARCH models in a second step. At all three data frequencies the persistence parameter d was estimated around 0.25-0.30 and significantly different from zero (the GARCH model) and one (the IGARCH model). Similarly, the asymmetry coefficient γ which was insignificant at a daily frequency is now significant at all three intraday frequencies. Negative innovations increase volatility more than positive ones of the same size. For the FIAGARCH models, the Ljung-Box statistics no longer reject the null hypothesis of uncorrelated squared standardized residuals. Also the values of the AIC and SIC are in favor of the FIAGARCH in comparison to the GARCH models at all intraday frequencies. Surprise announcements on NAP's have a negative and highly significant effect on EUA prices at all frequencies. This is in line with the expectation that unexpected positive allocation surprises will decrease demand for CO2 allowances and, hence, decrease prices. Finally, announcements that signal higher than expected economic growth, i.e. positive values of the standardized ifo-index, lead to significant increases in EUA prices. Table 4 presents the results for the analysis on the intraday level.

6 Conclusion

We have analyzed the movements in EUA prices from a daily and an intradaily perspective. The conditional variance of EUA prices is well described by a time-varying conditional heteroscedastic process. At an intraday level, we found evidence for a distinct seasonality in combination with long memory in the second conditional moment of the EUA prices. We show that a considerable fraction of EUA returns can be explained by changes in fuel prices at a daily frequency. Whether fuel price changes have positive or negative effects on EUA prices depends on switching opportunities to more or less carbon intensive production technologies. At the intraday level, EUA returns react immediately to major carbon relevant news announcements. Most importantly, the EC's decisions on the NAP's signiffcantly drive EUA returns at all frequencies. A one standard deviation positive surprise in the number of allocated allowances induces a 0.24% decrease in EUA

Table 4: Parameter Estimates for Intraday Data

	$R_t(10)$		$R_t(30)$		$R_t(60)$	
	GARCH	FIAGARCH	GARCH	FIAGARCH	GARCH	FIAGARCH
			Mean Equation			
μ	-0.0004 (0.0014)	-0.0005 (0.0014)	0.0015 (0.0042)	0.0018 (0.0042)	0.0040 (0.0086)	0.0027 (0.0085)
NAP	$-0.0187^{\star}$ (0.0090)	$-0.0174^{\star\star\star}$ (0.0066)	$-0.0199^{\star\star}$ (0.0093)	$-0.0206^{\star\star}$ (0.0101)	$-0.0348^{\star\star\star}$ (0.0109)	$0.0368^{\star\star}$ (0.0151)
CDM	-0.0013 (0.0014)	-0.0014^{+} (0.0009)	-0.0068^{+} (0.0044)	-0.0052 (0.0041)	-0.0117^{+} (0.0078)	-0.0081 (0.0082)
IFO	0.0019 (0.0013)	0.0019^{+} (0.0013)	$0.0091^{\star\star}$ (0.0030)	$0.0094^{\star\star\star}$ (0.0030)	$0.0095^{\star}$ (0.0056)	$0.0102^{\star}$ (0.0056)
			Variance Equation			
ω	$0.0010^{\star\star\star}$ (0.0002)	$0.0049^{\star\star\star}$ (0.0017)	$0.0033^{\star\star\star}$ (0.0012)	$0.0110^{\star\star\star}$ (0.0036)	0.0015 (0.0022)	$0.0223^{\star}$ (0.0133)
α	$0.0351^{\star\star\star}$ (0.0054)	$0.4965^{\star\star\star}$ (0.119)	$0.0498^{\star\star\star}$ (0.0105)	$0.3822^{\star\star\star}$ (0.0869)	$0.0390^{\star\star\star}$ (0.0124)	$0.4831^{\star\star}$ (0.1903)
γ	$0.0195^{\star\star}$ (0.0079)	$0.1233^{\star\star\star}$ (0.0292)	$0.0287^{\star}$ (0.0136)	$0.1383^{\star\star}$ (0.0393)	0.0251^{+} (0.0161)	$0.1509^{\star\star}$ (0.0638)
β	$0.9402^{\star\star\star}$ (0.0054)	$0.6136^{\star\star\star}$ (0.1124)	$0.9163^{\star\star\star}$ (0.0118)	$0.5647^{\star\star\star}$ (0.0909)	$0.9355^{\star\star\star}$ (0.0101)	$0.6209^{\star\star\star}$ (0.1758)
d	-	$0.2514^{\star\star\star}$ (0.0287)	-	$0.2992^{\star\star\star}$ (0.0371)	-	$0.2880^{\star\star\star}$ (0.0508)
AIC	0.139	0.114	1.244	1.229	1.966	1.954
SIC	0.142	0.117	1.251	1.236	1.980	1.968
$Q^2(20)$	79.37 [0.00]	14.52 [0.34]	45.66 [0.00]	20.30 [0.32]	21.15 [0.39]	12.29 [0.50]

Notes: The numbers in parentheses are Bollerslev-Wooldrige robust standard errors.

prices. Finally, the EUA prices also signifcantly react to news which indicate higher/lower then expected economic growth.

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