The European Commission and EUA Prices: A High-Frequency Analysis of the EC's Decision on Second National Allocation Plans

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Abstract

This paper deals with the empirical examination of price formation in the European Union Emissions Trading Scheme (EU ETS). We propose a model of expectation-formation, where agents anticipate the European Commission's decision on second National Allocation Plans. Based on high-frequency data on European Union Allowance (EUA) prices, we show that the model is able to capture the EUA price reactions immediately after the publication of the EC's decision on second NAPs. In particular, unexpected allocation leads to pronounced price reactions with appropriate signs. Moreover, we find evidence that the adjustment of EUA prices to new information might be prone to lags.

Keywords: Emission Allowances, Market Efficiency, EU ETS, European Commission, Communication, Expectations, Natural Experiment

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

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1. Introduction

A lot of research has been conducted on the optimal organisation of the European Union Emissions Trading Scheme (EU ETS), but only a comparatively small amount of research exists on price formation in the EU ETS. This is somewhat surprising, since the question of how information is incorporated in the European Union Allowance prices (EUA prices) is of great importance for a functioning European emissions market. It is well-known from the economic literature that a well-functioning market affects the liquidity, the transaction costs and ultimately the price of the goods traded. Functioning markets are able to create reliable price signals. In the case of the EU ETS or emission markets in general, prices that signal the true scarcity of emission allowances are crucial, since they are essential in identifying the cheapest abatement measures – the primary goal of emission markets.

This work investigates the functionality of the EU ETS by considering the adjustment of EUA prices to new information. There are several factors that affect the EUA price: oil, coal, gas, electricity prices, switching possibilities from coal to gas, to some extent the weather, the overall economic activity, and other issues that directly affect the supply or demand of EUAs and therefore the EUA price. The influence of the factors mentioned has already been empirically ascertained; see for example Mansanet-Bataller et al. (2007), Bataller and Pardo (2007), or Alberola et al. (2008). Despite this empirical evidence, there is room for further research. In particular, Bataller and Pardo (2007) find no significant effect of the approval of second National Allocation Plans on the EUA prices. Our contribution to the literature about the price formation in the EU ETS consists of a closer look at the link between EUA prices and one single fundamental factor, namely the determination of the size of the overall cap of the second commitment period. Unlike the studies mentioned above, we explicitly use expectations and high-frequency data. In other words, we are not content to simply deal with questions on whether or not there exists a link between the EUA prices and the selected fundamentals sometime during the day. Our aim is to reveal what happens to the EUA price directly after truly new information has hit the EU ETS. Admittedly, our study is subject to certain drawbacks, since we consider only one factor.

The remainder of the paper is organised as follows. Section 2 briefly describes the EU ETS in general and then focuses on those parts in particular that are most relevant for our analysis. Section 3 presents the model of expectation-formation with respect to the considered factor. In Section 4, we present the employed data and methodology used in the empirical analysis. Section 5 provides an empirical link between EUA price reactions and the unexpected allocation of EUAs at high-frequency. 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 US 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 cost and has been called the 'New Grand Policy Experiment' of market-based policies in environmental regulation.[4]

The scheme, also known in the literature as the European Union Greenhouse Gas Emissions Trading Scheme, requires selected industrial units to participate in the 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 the production of pulp and paper). The aviation sector will be included in the EU ETS from 2012 onwards. Apart from carbon dioxide (CO_2) – which accounts for the biggest share of covered gases – five other gases (methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6)) that are supposed to have an impact on climate change are covered by the scheme. One emission allowance grants the participating installation (or one of its other holders) the right to emit one tonne of carbon dioxide equivalent (tCO_2e) during a specified commitment phase.[5]

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 for each commitment phase is defined by the so-called 'National Allocation Plans' that are set up by the member states and approved by the European Commission. We call these various plans 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, grandfathering having been the most common allocation rule in the first two phases. According to the European Commission (European Parliament and Council, 2008), auctioning should be the basic principle for allocation from 2013 onwards. The allowances are freely tradable after they have been allocated to the 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 any remaining number of allowances can sell them on the market. Inversely, any installation that lacks allowances has to purchase them on the secondary market, e.g. 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

[4] Kruger and Pizer (2004).
[5] European Parliament and Council (2003).

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 is relatively small compared to energy markets. The annual emission cap equals 2,299 million tCO_2e in the first commitment period and 2,081 million tCO_2e in the second. The cap (as an approximation of outstanding EUAs) and the average annual EUA price suggest an annual market value of €30 billion in the first commitment and of €50 billion in the second commitment period, respectively.[6] The European electricity market, on the other hand, has an estimated annual market value of €224 billion; see Farrimond (2008).

Within the second commitment period, all participating installations are allowed to use other eligible instruments, such as the so-called Certified Emission Reductions (CERs) or the 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 'Joint Implementation'. Both mechanisms are defined under the Kyoto Protocol and refer largely either to projects that are conducted between developed and developing countries or amongst the developed countries only. The expected number of available CERs until 2012 amounts to approx. 1,537 million tCO2e (307 million tCO2e per annum, according to the November 2008 forecast of 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 Joint 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 instruments (for example Germany, Spain, and Lithuania). All member states in total (excluding Malta) must not surrender more than 278 million CERs/ERUs annually – 13 percent of the EU-wide emission cap. Although the market for other eligible instruments is not limited 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 EU ETS installations.

The issuance of EUAs and the carrying out of emission reduction projects in exchange for CERs or ERUs comprise 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 of EUAs is regulated and supervised by each member state and its individual regulating authorities, rather than by the

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

EC – although the latter sets the framework. The most active trading takes place OTC, accounting for 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. Apart from an active EUA spot market there is also a vibrant derivatives market, where futures, options, and other derivatives on EUAs are traded. The most liquid EUA spot market is BlueNext in Paris, which attracts approx. 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 approx. 90 percent of the daily turnover in EUA futures. The trading of other derivative instruments written on EUAs is negligible for the time being. Other exchanges that offer trading in EUAs 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 (2009).

Trading rules on all organised EUA spot markets are largely identical. Trading consists of continuous trading sessions on working days. EXAA is an exception among these markets with one auction per working day. The minimum price movement is 1 Euro cent on all spot markets, and all quoted prices refer to 1 EUA. The number of EUAs per trade is an integer multiple of 1,000, 500, or 1 EUA. 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 1,000 EUAs. For a detailed comparison of all trading rules both of EUA spot and EUA futures markets see Mansanet-Bataller and Pardo (2008).

3. Model of Expectation-formation

An assessment of the effect 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 general, it is hard to observe or to obtain exact information about individual expectations in real markets. 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 interest. Another possibility is to use a model of expectation-formation, where expectations of

market participants are a function of observable variables. The latter method is applied in this work.

We concentrate our analysis on announcements about the EC's decision on second NAPs. We select these announcements because they constitute a natural experiment. In particular, the overall cap in the EU ETS is not set by a single decision, but rather by several decisions that involve each member state and the EC. Based on the Directive 2003/87/EC, as amended by Directive 2004/101/EC, each member state designs an 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.[7] Subsequently, the plan is published, undergoes a public consultation, and notified to the EC and other member states. Within three months of notification, the EC accepts or rejects the plan, or any aspect thereof, on the basis of the 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 allocating EUAs to a participating installation by the member states is only allowed 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 EC decisions on NAPs and the whole approving process can be considered as transparent. It is a natural experiment, since there are several observations (EC decisions) on the same subject, namely the determination of the size of the overall cap in the EU ETS.

The difficulty in our analysis lies in finding the right rule for the expectation-formation of market participants. We let the expectations be a function of the total number of EUAs that has been approved in the first NAPs.[8] Obviously, this procedure assumes that market participants disregard whatever information member states have notified to the EC in their NAPs for the second commitment period. A thorough investigation of the EU ETS framework, the study of related press releases, and interviews with market participants, have shown that it is a widely accepted feature of the EU ETS to treat first NAPs as a point of reference. We assume that market participants in the EU ETS form their expectations regarding the EC's decision on second NAPs according to the following formula:

$$E\left[y_i \mid F_{i-}\right] = \begin{cases} (1-cut)\cdot X_i & \text{if} \quad y_i^{submitted} > (1-cut)\cdot X_i \\ y_i^{submitted} & \text{if} \quad y_i^{submitted} \le (1-cut)\cdot X_i, \end{cases}$$

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

[8] We tried another possibility of expectation formations where X_i equals the submitted number of EUAs for the second commitment period or the total realised emissions of participating institution in 2005. However, the results show that neither of these alternatives lead to better explanation of EUA price reactions.

where $E[y_i \mid F_{i-}]$ represents the conditional expectation of market participants on the EC's decision on the total number of EUAs in the second NAP of member state i, with $i = 1, 2, \ldots, 27$. All 27 member states take part in the emissions trading; therefore there are an equal number of decisions, expectations, and announcements. X_i is the total number of EUAs in the first NAP of the member state *i*, which is known to all market participants prior the decisions. *cut* is a real constant between 0 and 1 that defines the percentage reduction of the total number of EUAs compared to that of the first commitment period. It can be considered as a lump cut of the first NAPs. $y_i^{submitted}$ is the total number of EUAs in the second NAP of the member state *i*, which was notified to the EC. F_{i-} is the information set of all market participants 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 communicated to the EC (our escape clause). Please note that we ignore any feedback effects on expectations.

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 real constant between 0 and 1. This assumption results directly from the tough EC statements that only tight caps will be allowed; see Barroso (2006a). Of course, these assumptions are not true for every market participant. But for convenience sake, we set *cut* to a constant and assume that it is an average of individual lump cuts of all market participants. This also means that the calculated conditional expectation $E[y_i \mid F_{i-}]$ 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 thought is supported by a publicly cited analyst, who expected a 10 per cent from first NAPs; see PointCarbon (2006b). The estimate of the cited analyst 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, each 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 'fair' as stated by José Manuel Barroso before the first official release of the 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 5. Unless stated otherwise, the expectations of market participants in the following always refer to a lump cut of 7.5 per cent.

4. Data and Methodology

4.1. Data

4.1.1. Price Data

Our investigations are based on high-frequency data obtained from ICE Futures/European Carbon Exchange (ECX), the leading exchange for trading in EUA futures. The data covers the period between 22/04/2005 and 01/09/2008 and contains all transactions of all offered financial instrument contracts that are based on EUAs or CERs and traded on ICE Futures. Trading on ICE Futures takes place every working day between 7:00 and 17:00 GMT/BST. The raw files contain a total of 239,648 transaction records. Each transaction record holds the name of the product (e.g. ICE ECX CFI Futures), the time stamp measured in GMT and recorded exactly up to the seconds, the maturity of the contract (e.g. December 2005), the transaction price in Euro, the quantity, the order book side of the transaction (bid/offer), the trade type (e.g. registered OTC transaction, screen trades, etc.), and the order identification number of the trade (since 01/08/2007). The distribution of different trade types are displayed in Table 1.

[insert Table 1 about here]

The investigation of EUA price reactions does not require all transactions that are available in the raw files. Hence, we discard all transactions that are not regular on-exchange trades. We also delete all transactions that do not refer to the December 2008 futures contract and remove any transaction with a price greater than 40 euros. This procedure leaves us with 131,786 transactions that cover the period between 05/07/2005 and 01/09/2008. The reasons for our selection are twofold. First, we concentrate solely on regular on-exchange transactions (screen transactions), because different transaction types could be driven by different price formation processes. Second, the December 2008 futures contract is the most liquid futures contract that is relevant for our analysis – its price refers to the EUAs allocated to the second commitment period. The deletion of transactions with prices greater than 40 euros corrects for outliers (relevant for 24 transactions).

After the deletion of unnecessary transactions we calculate equidistant prices using the remaining data. It is possible to use irregularly spaced price data in our analysis, but we refrain from this possibility in our paper. The construction of equidistant prices largely follows Andersen and Bollerslev (1997). Moreover, we use transaction prices instead of mid-quotes and fix the equidistant intervals to 10 minutes. The equidistant price is calculated for each 10-minute interval during the trading session as the mean of the preceding and immediately following prices. We neglect any distance of the transaction prices from the

equidistant point in time. The resampling reduces the number of nodes to 39,467 (61 equidistant prices per trading day times 647 trading days).

4.1.2. Announcement Data

In several cases the EC approved the NAPs on condition that changes are made to the total number of emission allowances. In few cases the EC proposed informal emission caps, which the member states either accepted without any complaints or dismissed by withdrawal of the proposed NAP shortly before the decision. Thus, given the setting procedure of the overall cap and the described occurrences, there are in total 27 (conditional) NAP approvals, six decisions on amendments, and three information leakages – publications of the EC's decisions before the announcement of the actual decision (which happened in the case of Germany, Belgium, and Ireland). We exclude amendments and information leakages from the analysis for reasons given below. Our data on NAP announcements therefore consists of 27 announcements that were made between 20/11/2006 and 26/10/2007 (see Table 2 in the appendix). The announcement of the EC's decisions was sporadic, but scheduled. In our setting, the point in time at which the decisions were announced equals the time they were made public via a known news agency in this market, namely the newswire PointCarbon. Other data, especially the number of approved EUAs in the first and second NAPs, were gathered from the EC's website and the press releases.

Most markets are not perfect, and neither is the EU ETS. Our model of expectation-formation depends on F_{i-}. In a perfect experiment we would not let F_{i-} change between each decision of the EC. Unlike perfects experiments, we have to deal with information that leaks out to the market. There were, to our knowledge, at least three information leakages in the considered period, two of which are relevant for our analysis.[9] In the case of Germany, an internal EC request to cut the submitted number of Germany's EUAs hit the market in an uncontrolled manner (see Ehrenstein and Wetzel 2006). In the case of Belgium, the official EC decision leaked out to the market one day before the official announcement (see DeMorgen 2007). 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 themselves, for two reasons: Firstly, the accurate timestamp of the leak is not known, even though it would be reasonable to set it at the time of market opening, and secondly, EUA prices could react differently to information leakages than to scheduled announcements. The third information leakage occurred in the case of Ireland, where the EC's decision on the amended NAP reached the market before the official announcement. The amendments are not considered because the stated expectation formation applies to the approvals only. Therefore, it is not necessary to control for the leak in the case of Ireland. We define the unexpected part of the announcements as $S_i = E\left[y_i \mid F_{i-}\right] - y_i$, with y_i as the total

[9] For information leakages that occurred before the period we consider; see for example PointCarbon (2006a).

number of EUAs in the second NAP of the member state i that has been accepted by the EC. Positive S_i implies an unexpected cut or under-allocation (a reduction compared to Phase I) and negative S_i unexpected over-allocation of EUAs.

Based on our simple model of expectation-formation, market participants expect on average an allocation of 78 million EUAs per NAP, with a standard deviation of approx. 103 million. The smallest number of EUAs is expected for Malta (2.49 million), and the highest for Germany (465 million). The decision of the EC, conversely, involves on average 77 million EUAs per NAP. The smallest deviation between the number expected and the number actually approved – among all considered values for cut in Table 3 – amounts to 0.98 million EUAs with a standard deviation of 5.9. The most pronounced estimation errors of market participants occur in the case of UK and Poland. In the former case, there is an overestimation of the reduction by 19.3 million EUAs (S_i = -19.3), in the latter case an underestimation by 12.7 million EUAs (S_i = 12.67). Further summary statistics of both the conditional expectation and of the surprises are displayed in Table 3.

[insert Table 3 about here]

The feature of announcements requires an aggregation of the data. Seventeen of 27 decisions were made on four days and reached the market within a few minutes in rapid succession. In particular, these announcements hit the EU ETS successively at averaged 4-minute intervals (with a standard deviation of 3.3 minutes). The liquidity of the on-exchange EUA futures, especially at the beginning of the considered announcement period, was not high enough to allow for a consideration of every single announcement. Therefore, we summarise 17 announcements to four (artificial) announcements so that there is only one announcement per trading day. In doing so, we are left with 14 announcements that we employ in our regressions. The aggregation of relevant quantities occurs in straightforward fashion; on all days with more than one announcement on second NAPs the time stamp of the compiled announcement equals the time stamp of the first announcement on second NAPs. Other aggregated quantities are defined as the sum of their respective individual counterparts. For instance, the first 10 announcements on 29/11/2006 displayed in Table 2 are combined into one announcement, in which the arrival time, the conditional expectation, the realisation, and the surprise equal 11:02:00 GMT, 852.01, 860.15, and -8.13.

4.2. Methodology

We use simple cross-sectional methods similar to Almeida et al. (1998) to assess the EC's decisions on second NAPs. Unless the proposed expectation-formation in Section 3 is incorrect, there should be no empirical relationship between EUA price reactions and our

calculated surprises; hence price changes immediately after announcements should be random. The central equation that we use in our analysis is given by the following formula,

$$r_{t_i+k} = \alpha + \beta \cdot S_i + u_{t_i+k} .$$

We define r_{t_i+k} as the difference of two EUA prices, $p_{t_i+k} - p_{t_i}$, with t_i representing the first equidistant 10-minute interval after the considered new information *i* hits the market.[10] k is defined as the elapsed time after the news arrival measured in minutes and u_{t_i+k} is the appropriate error term. The investigation of price reactions is performed for several values of *k*. In the first step, we fix *k* at *T*- t_i minutes, where T equals the point in time at the day of the announcement at which the trading session closes. In the second step, we fix k at 10, 20, 30,…, 480 minutes.

The equation is basically derived from the efficient market hypothesis and states that the EUA price changes are a function of the surprises. If the model of expectation-formation is sufficiently accurate, we expect the estimate of β to be positive; positive surprises are expected to increase the EUA price ($S_i > 0$ implies a reduction of the supply of EUAs). The influence of surprises is considered to be symmetric. Furthermore, we expect the estimate of α to be statistically not different from zero. This seems to be a standard assumption at first glance, but is in fact the point where the ad hoc values for *cut* come into play. Consistent or unbiased expectation-formation of market participants implies that market participants should not systematically under- or overestimate the EC's decision. Therefore, if we assume that our linear expectation-formation is unbiased and that surprises lead to price reactions if and only if they are not zero, it is reasonable to fix *cut* at a value that leads to $\alpha = 0$.

5. Empirical Results

The following analysis can be considered as an empirical test of the hypothesised expectation-formation. Moreover, the obtained results highlight important features of price formation in the EU ETS. They disclose the impact of news on the EUA price and indicate the speed of the adjustments.

[10] All results are robust to the use of logarithmic price changes rather than absolute price changes as the dependent variable.

The results of our investigations are promising. Unexpected cuts lead to price increases and unexpected over-allocation to price decreases. Therefore, the reactions are in line with our expectations and are summarised in Table 4 and Figures 1 and 2. In particular, the effect of an unexpected cut of 1 million EUAs leads to an EUA price increase of 4.6 Euro cents when we consider the price changes after the announcement instant up to the closure of the trading session at the day of the announcement ($k = T - t_i$). The effect is significant at all reasonable significance levels with a *t*-value of 5.3. The 95 per cent confidence interval of the impact ranges from 2.7 to 6.4 Euro cents. The estimated constant equals 1 Euro cent, but is not statistically different from zero given its significance level of almost 15 per cent. The significance of the intercept is in line with our expectations. Although the RESET test suggests no omitted variables, we think that it would be beneficial to control for other factors that are also supposed to affect the EUA price in the short run, for example the oil price. Finally, our surprises seem to explain the variation of considered EUA price changes fairly well – the coefficient of determination equals 70 per cent.

The impact of surprises according to values of *k* up to 480 minutes are summarised in Figures 1 and 2. The figures suggest that the market participants need six hours to process the EC's decisions on second NAPs. The impact, though rather small immediately after the releases, is nonetheless positive and significant. It moves slightly below 2 Euro cents within the first 160 minutes before it actually rises to the pronounced level of 4 Euro cents – at 360 minutes after the announcement instant. Thereafter the impact seems to fade away, as subsequent random fluctuations or other possible factors become more present. On the other hand, the estimated intercept is small and negative, albeit significant at the 10 per cent level when considering EUA price changes over intervals of up to 120 minutes. Most of the other considered intervals of up to eight hours after the announcement instant suggest an insignificant intercept. Since we expected to see an adjustment within few minutes, the result is a little surprising.

All the results presented so far rest upon the value of *cut* that we set ad hoc to 7.5 per cent. Of course, this choice can be regarded as arbitrary, but it is actually supported by the data. If we assume that market participants are to some extent not rational and drop the escape clause in the stated expectation-formation, we are able to estimate *cut* by simply regressing the approved total number of EUAs in the second NAPs on the already known number of EUAs in the first NAPs. In this case, the estimated slope coefficient equals 1-*cut* and the residuals can be regarded as surprises or forecasting errors. We summarise the results from these regressions in Table 5, where we use the 14 compounded announcements in order to obtain an estimate of the impact on EUA prices that is comparable to the reported numbers in Table 4. The obtained estimate of 1-*cut* equals 0.919, suggesting a value of 8.1 per cent for *cut*, which is not that far from the ad hoc value of 7.5 per cent. The estimate is significant at all reasonable levels and its 95 per cent confidence interval spans the set of real numbers from 0.900 to 0.939. The estimated impact of calculated forecasting errors on the EUA price

changes amounts to 3.3 Euro cents and is also significant. The appropriate 95 per cent confidence interval includes all real values from 1.5 to 5.0 Euro cents.

Despite the low number of observations, the achieved results strongly support our model of expectation-formation. The high-frequency EUA price reactions to the EC's decision on second NAPs are pronounced and show the appropriate sign; not only when the EUA price changes are measured over the time interval from the announcement instant to the point in time of the trading session closure, but also over other considered intervals up to eight hours after the announcement instant. We have to note that the overall picture of the estimated impact does not change when we consider other values of *cut* between 0 and 10 per cent. In most cases, the estimated impact of the EC's decision is positive, significant, and increases persistent up to eight hours after the announcement instant. Again, the random fluctuations of EUA prices do not become evident until six hours after the announcement instant. The estimated intercept is small, negative, and insignificant when measuring price changes over intervals up to 120 minutes. Therefore, the results seem to be robust across different post-announcement intervals and reasonable lump cut values.

6. Conclusions

This paper investigates price formation in the European Union Emissions Trading Scheme (EU ETS). The main question of the paper is not whether there is a link between European Union Allowance prices (EUA prices) and its fundamentals sometime during the day. Rather, it aims to investigate what happens to the EUA price, once really new information hits the EU ETS.

The focus of the analysis presented lies on the reactions of EUA prices to the EC's decisions on second NAPs. Since prices should react only to unexpected new information, a model of expectation-formation, where agents anticipate the decision of the EC on second NAPs, is provided. A subsequent empirical analysis shows that an unexpected allocation of emissions allowances leads to pronounced EUA price reactions with appropriate signs. In particular, unexpected cuts lead to price increases and unexpected over-allocation to price decreases. The price impact amounts to 4.6 Euro cents per 1 unexpected mega tonne of CO_2. In other words, an unexpected reduction of 1 million EUAs in the second NAP of a member state on the part of the EC leads to an EUA price increase of 4.6 Euro cents. The adjustments of EUA prices to new information are slow. It takes approximately six hours until the EC's decisions are fully incorporated into the EUA prices.

Moreover, there is evidence for information leakages in the EU ETS. There were at least three information leakages in the considered period. In the case of Germany, an internal EC request to cut the submitted number of Germany's EUAs hit the market in an uncontrolled manner. And in the case of Belgium, the official decision of the EC leaked out to the market one day before the official announcement. The third information leakage occurred in the case of

Ireland, where the EC's decision on the amended Irish NAP reached the market before the official announcement.

The obtained results allow the following conclusions to be drawn. First, the empirical test of the hypothesised expectation-formation strongly supports the model. The model is able to capture the EUA price reactions immediately after the publication of the EC's decision on second NAPs. Second, the EU ETS seems to function without serious drawbacks. In particular, EUA prices adjust in the right direction, as our model of expectation-formation would suggest. Hence, there is no evidence that EUA prices are disconnected from the considered fundamental factor, namely the overall supply of EUAs in the second commitment period. However, the slow adjustment of EUA prices to new information suggests that there is still room for price formation improvement in the EU ETS. An adjustment of EUA prices within six hours after the announcement instant is not necessarily a sign of market efficiency.

Several open questions remain for further research. The first issue is, of course, the reason for the slow adjustment of EUA prices to new information. Further methods, especially time-series methods, and investigations of the market structure should provide more firm statements. Other questions such as the symmetry of EUA price reactions or the influence of leaked announcements deserve a thorough analysis. The main question in this context is of course the market efficiency within the EU ETS. Finally, the investigation of the relation between other fundamentals and EUA prices at the high-frequency level, e.g. oil, coal, gas, or electricity prices, should provide a valuable understanding of price formation in the EU ETS.

Appendix

Table 1: Description and distribution of trade types[11]

Trade type	Trade type code	Number of observations	Percentage	Cumulative percentage
Non-Cross Contra trade (On-screen second day correction trade between two different Clearing Members)	F	214	0.09	0.09
Block trade	K	111	0.05	0.14
Exchange of Futures for Physical/Exchange of Futures for Swaps trade (EFP/EFS trade)	O	63,370	26.44	26.58
Exchange of Futures for Swaps trade (EFS trade)	S	29	0.01	26.59
Screen trade, Contra trade (= regular on-exchange trade)	T	171,134	71.41	98
Bilateral Off-Exchange	V	2	0	98
Screen traded Cross trade (a trade between the two clients with the same Clearing Member)	X	4,569	1.91	99.91
Cross Contra trade (On-screen second day correction trade between clients of the same Clearing Member)	Y	219	0.09	100
	Total	239,648	100	

Table 2: Data on NAP announcements

Timestamp (GMT)	Country	NAP I	submitted NAP II	expected NAP II	NAP II	Surprise
29-11-2006 11:02:00	UK	245.3	246.2	226.90	246.20	-19.30
29-11-2006 11:03:00	Greece	74.4	75.5	68.82	69.10	-0.28
29-11-2006 11:04:00	Ireland	22.3	22.6	20.63	21.15	-0.52
29-11-2006 11:06:00	Lithuania	12.3	16.7	11.38	8.80	2.58
29-11-2006 11:07:00	Sweden	22.9	22.3	21.18	22.80	-1.62
29-11-2006 11:08:00	Luxembourg	3.4	4	3.15	2.70	0.45
29-11-2006 11:09:00	Latvia	4.6	7.7	4.26	3.30	0.96
29-11-2006 11:09:00	Slovakia	30.5	41.3	28.21	30.90	-2.69
29-11-2006 12:10:00	Malta	2.9	2.49	2.49	2.10	0.39
29-11-2006 12:24:00	Germany	499	465.0	465.00	453.10	11.90
16-01-2007 12:36:00	Belgium	62.1	58.51	58.51	58.50	0.01
16-01-2007 12:43:00	Netherlands	95.3	90.4	88.15	85.80	2.35
05-02-2007 10:57:00	Slovenia	8.8	8.3	8.14	8.30	-0.16
26-02-2007 11:10:00	Spain	174.4	152.6	152.60	152.30	0.30
26-03-2007 10:27:00	Poland	239.1	284.6	221.17	208.50	12.67
26-03-2007 10:35:00	Czech Republic	97.6	101.9	90.28	86.80	3.48
26-03-2007 10:43:00	France	156.5	138.3	138.30	132.80	5.50
02-04-2007 15:30:00	Austria	33	32.8	30.53	30.70	-0.17
16-04-2007 10:38:00	Hungary	31.3	30.7	28.95	26.90	2.05
04-05-2007 10:01:00	Estonia	19	24.38	17.58	12.70	4.88
15-05-2007 10:01:00	Italy	223.1	209	206.37	195.80	10.57
04-06-2007 10:02:00	Finland	45.5	39.6	39.60	37.60	2.00
18-07-2007 10:54:00	Cyprus	5.7	7.12	5.27	5.48	-0.21
31-08-2007 10:02:00	Denmark	33.5	24.5	24.50	24.50	0.00
22-10-2007 10:04:00	Portugal	38.9	35.9	35.90	34.80	1.10
26-10-2007 10:20:00	Bulgaria	42.3	68.6	39.13	42.30	-3.17
26-10-2007 10:21:00	Romania	74.8	97.55	69.19	75.90	-6.71

The submitted and expected values for Germany and Belgium are replaced by the leaked out values. The value of *cut* in calculating expectations equals 7.5%. Denmark, Finland, France, Malta, Portugal, and Spain are the member states for which the escape clause of the proposed expectation-formation applies.

[11] Detailed description of trade types is given in ICE Futures (2008a), ICE Futures (2008b), and ICE Futures (2008c).

Table 3: Descriptive statistics of conditional expectations and surprises

Statistic / *cut*	0.00%	2.50%	5.00%	7.50%	10.00%
Conditional expectations of market participants					
Mean	80.80	79.97	79.08	78.01	76.78
Standard Deviation	104.78	104.15	103.57	102.88	102.09
Minimum	2.49	2.49	2.49	2.49	2.49
Maximum	465.00	465.00	465.00	465.00	465.00
Surprise					
Mean	3.77	2.94	2.05	0.98	-0.25
Standard Deviation	6.64	6.05	5.88	5.93	6.31
Minimum	-1.10	-7.03	-13.17	-19.30	-25.43
Maximum	30.60	24.62	18.65	12.67	11.90

Table 4: The impact of EC decisions on second NAPs on high-frequency EUA price changes

Dependent variable: EUA price changes						
	Coef.	Std. Error	t	P>|t|	95% Confidence-Interval	
Alpha	-0.099	0.064	-1.550	0.147	-0.239	0.040
Beta	0.046	0.009	5.320	0.000	0.027	0.064

Ramsey-RESET-Test	Overall-F-Test	Coefficient of determination and number of observations
F(3.9) = 1.97	F(1,12)=28.33	R2 = 0.70
Prob > F = 0.1894	Prob > F = 0.0002	Nobs = 14

The value of *cut* equals 7.5%. The dependent variable is the EUA price change between the announcement instant and the closing of the trading session. The independent variable is the unexpected part S_i defined in Section 4.1.2.

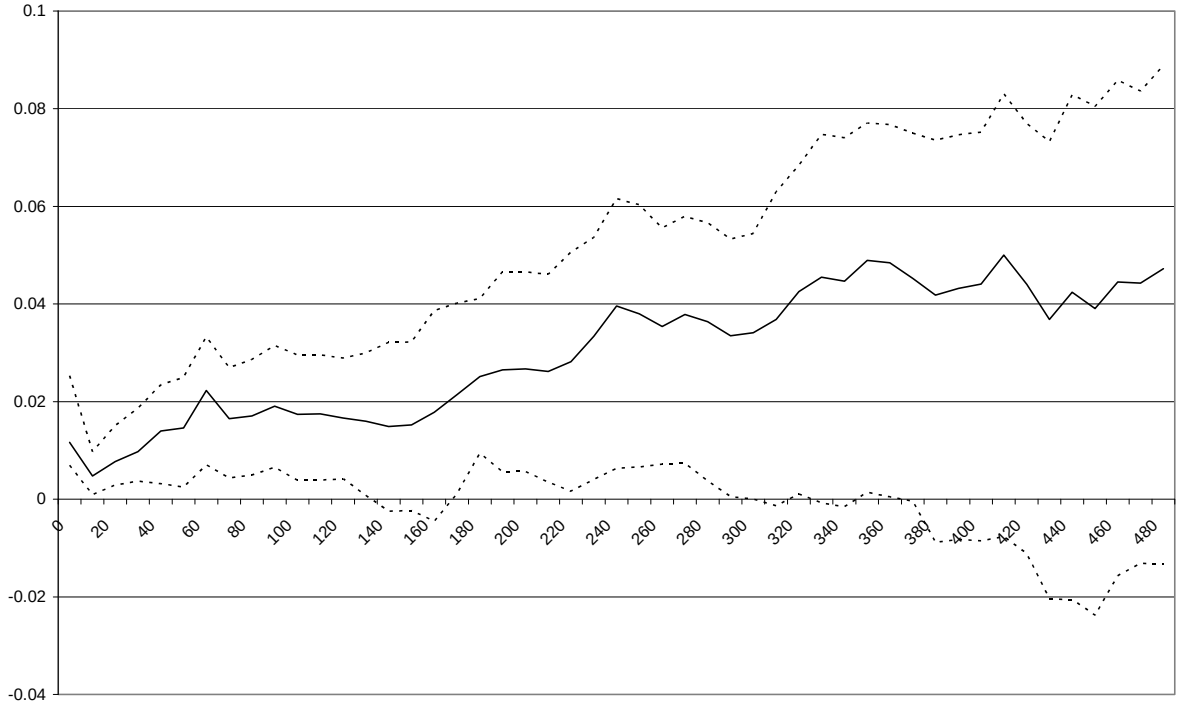
Table 5: The impact of EC decisions on second NAPs on high-frequency EUA price changes using a bounded version of the expectation-formation

Dependent variable: Total number of approved EUAs in the second NAPs						
	Coef.	Std. Error	t	P>|t|	95% Confidence-Interval	
1-*cut*	0.919	0.009	102.640	0.000	0.900	0.939
Dependent variable: EUA price changes						
	Coef.	Std. Error	t	P>|t|	95% Confidence-Interval	
Alpha	0.091	0.075	1.200	0.253	-0.074	0.255
Beta	0.033	0.008	4.120	0.001	0.015	0.050

Ramsey-RESET-Test	Overall-F-Test	Coefficient of determination and number of observations
F(3.9) = 3.97	F(1,12)=17	R2 = 0.59
Prob > F = 0.0467	Prob > F = 0.0014	Nobs = 14

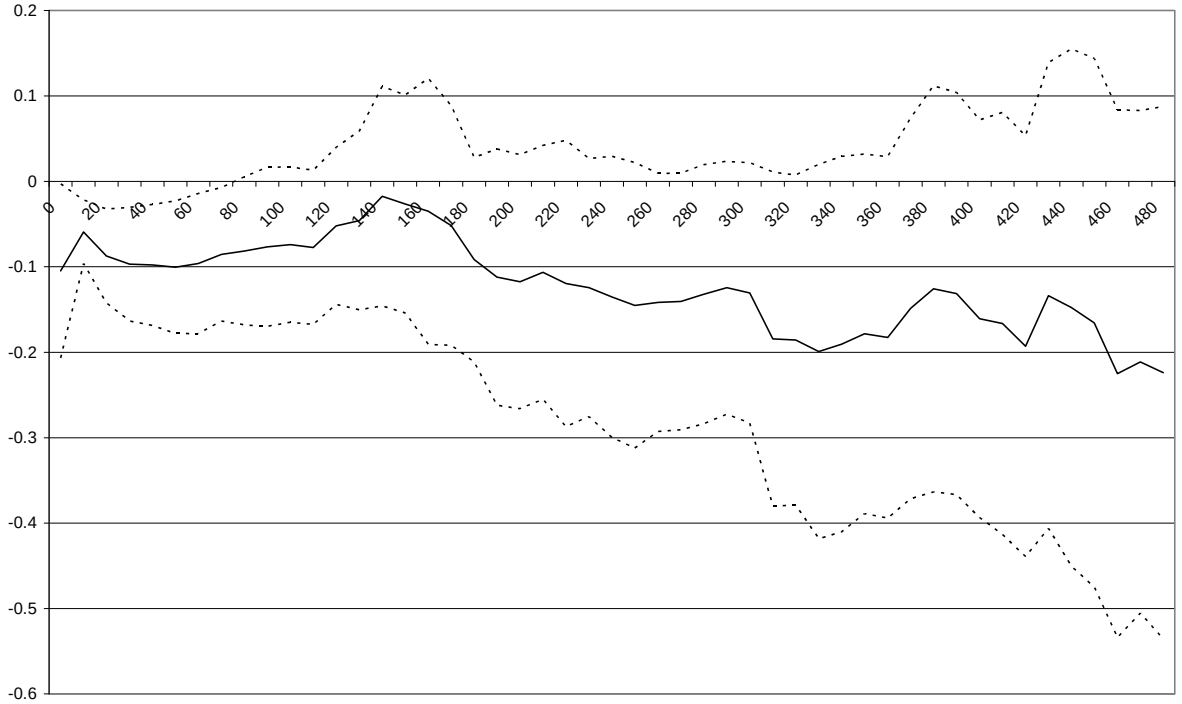
First regression: The dependent variable is the total number of approved EUAs in the second NAPs. The independent variable is the total number of EUAs in the first NAPs. The coefficient of determination equals 0.9988. Second Regression: The dependent variable is the EUA price change between the announcement instant and the closing of the trading session. The independent variable is the forecasting error (the residuals) from the first regression. Please note that residuals from the first regression were multiplied by minus 1 for the purpose of comparison.

Figure 1: The persistence of the estimated impact of EC decisions on EUA price changes



The figure presents the estimates of β (solid line) together with the 95 per cent confidence interval (dotted line) of the cross-section regression of surprises from Table 2 on EUA price changes over different intervals. The intervals are measured in minutes after the announcement instant.

Figure 2: The bias of the estimated impact of EC decisions on EUA price changes



The figure presents the estimates of α (solid line) together with the 95 per cent confidence interval (dotted line) of the cross-section regression of surprises from Table 2 on EUA price changes over different intervals. The intervals are measured in minutes after the announcement instant.

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