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The Informational Efficiency of the European Carbon Market

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ABSTRACT

This thesis examines the informational efficiency of the European carbon market based on the European Union Emissions Trading Scheme (EU ETS). The issue is approached from three different perspectives. I explore whether the volatility embedded in carbon options is a rational forecast of subsequently realized volatility. Then, I investigate if, and to what extent, new information about the structural and institutional set-up of the market impacts the carbon price dynamics. Lastly, I examine whether the European carbon market is relevant for the firm valuations of covered companies.

First, perhaps because the market is new and derivatives' trading on emission allowances has only started recently, carbon options have not yet been extensively studied. By using data on options traded on the European Climate Exchange, this thesis examines an aspect of market efficiency which has been previously overlooked. Market efficiency suggests that, conditional upon the accuracy of the option pricing model, implied volatility should be an unbiased and efficient forecast of future realized volatility (Campbell et al., 1997). Black (1976) implied volatility and implied volatility estimates directly surveyed from market participants are used in this thesis to study the information content of carbon options. Implied volatility is found to be highly informative and directionally accurate in forecasting future volatility. There is no evidence, however, that volatility embedded in carbon options is an unbiased and efficient forecast of future realized volatility. Instead, historical volatility-based forecasts are shown to contain incremental information to implied volatility, particularly for short-term forecasts. In addition, this thesis finds no

evidence that directly surveyed implied volatility estimates perform better as a forecast of future volatility relative to Black's (1976) estimates.

Second, the market sensitivity to announcements about the organizational and institutional set-up of the EU ETS is re-examined. Despite their importance for the carbon price formation, demand-side announcements and announcements about the post-2012 framework have not yet been researched. By examining a very comprehensive and updated dataset of announcements, this thesis adds to the earlier works of Miclaus et al. (2008), Mansanet-Bataller and Pardo (2009) and Lepone et al. (2011). Market participants are found to rationally incorporate new information about the institutional and regulatory framework of the emissions trading scheme into the carbon price dynamics. However, they seem to be unable to accurately assess the implications of inter-temporal banking and borrowing on pricing futures contracts with different maturities. The impact of macroeconomic conditions on the market responsiveness is investigated by splitting the dataset into subsamples according to two alternative methods: 1) a simple split into pre-crisis and full-crisis time periods, and 2) according to a Bai-Perron structural break test. Evidence is found that in the context of economic slowdown and known allowances oversupply, the relationship between the carbon price and its fundamentals (institutional announcements, energy prices and extreme weather) breaks down. These findings are consistent with the arguments in Hintermann (2010), Keppler and Mansanet-Bataller (2010) and Koop and Tole (2011) that carbon price drivers change in response to the differing context of the individual trading periods.

Third, the role of carbon performance in firm valuation is understudied. Since companies were not obliged to disclose their carbon emissions prior to the launch of the EU ETS, there exists little empirical evidence of the effect of carbon performance on market value. Earlier studies of the European carbon market have only focused on the impact of ETS compliance on the profitability and competitiveness of covered companies (e.g. Anger and Oberndorfer, 2008). There is also little research on how the newly available emissions data has altered the carbon performance of companies. This thesis addresses these gaps in the literature by examining the stock price reactions of British and German firms on the day of verified emissions release under the EU ETS over the period 2006 – 2011. An event study is conducted using a Seemingly Unrelated Regressions model to deal with the event clustering present in the dataset. Limited evidence is found that investors use information about the carbon performance of companies in their valuations. The information contained in the carbon emissions reports is shown to be somewhat more important for companies with high carbon-intensive operations. This thesis finds no conclusive evidence that the cap-and-trade programme has been able to provide regulated companies with enough incentives to de-carbonize their operations. The market does not punish companies which continue to emit carbon at increasing rates or reward companies which improve their carbon performance.

In brief, the results of the thesis suggest that the market is not fully efficient yet. Inefficiently priced carbon options may allow for arbitrage trades in the market. The inability of investors to incorporate rules on inter-temporal banking and borrowing of allowances across the different trading periods leads to significant price reactions when there should be none. A recessionary economic environment and a known oversupply of emission allowances have led to a disconnect between the carbon price and its fundamental drivers. And, lastly, the signal embedded in the carbon price is not strong enough to invoke investor action and turn carbon performance into a standard component of investment analysis.

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GLOSSARY OF TERMS AND ACRONYMS

Acronym	Term	Meaning
UNFCCC	United Nations Framework Convention on Climate Change	The overall framework for intergovernmental efforts to address climate change. The Kyoto Protocol is an extension of the Convention, whereby industrialized countries legally commit themselves to reduce their carbon emissions.
COP/MOP	Conference of Parties/Meeting of Parties	The Conference of the Parties is the governing body of the UNFCCC.
EU ETS (ETS)	European Union Emissions Trading Scheme	EU ETS is a multi-country emissions trading scheme introduced in the European Union in order to help Member States meet the emission reductions pledged under the Kyoto Protocol.
CDM	Clean Development Mechanism	Under the Clean Development Mechanism, developed countries can earn carbon credits towards meeting their Kyoto reduction targets by investing in carbon-reducing projects in developing countries.
JI	Joint Implementation	Under the Joint Implementation Mechanism developed countries can earn carbon credits towards meeting their Kyoto reduction targets by investing in carbon-reducing projects in other developed countries.
EUA	European Union Allowance	EUAs are tradable carbon emission credits which allow installations regulated under the EU ETS to emit a metric tonne of carbon into the atmosphere.
CER	Certified Emission Reduction	A project-based carbon offset created under the CDM.
ERU	Emission Reduction Unit	A project-based carbon offset created under the JI.
CITL	Community Independent Transaction Log	An electronic system which connects the standardized national registries of all EU Member States covered by the emissions trading scheme.
ITL	International Transaction Log	An electronic system which connects the standardized national registries of all Parties to the Kyoto Protocol.
NAP	National Allocation Plan	National Allocation Plans set out the amount of CO_2 emission allowances allocated to each EU Member State under the emissions trading scheme.
VER	Verification	An annual procedure whereby all covered installations report their actual emissions during the year.

CHAPTER 1 INTRODUCTION

1.1. MOTIVATIONS

The development and growth of carbon dioxide (CO_2) emissions trading schemes is perhaps the most visible result of worldwide efforts to mitigate climate change and has resulted in the emergence of CO_2 (hereafter carbon) as a mainstream commodity. Emissions trading is the pillar of the Kyoto Protocol (United Nations, 1998) and it has enabled the financial market to put a price on the right to pollute the atmosphere. These rights are tradable both at country and company levels. Although voluntary carbon markets and regional initiatives have been in existence for a while, carbon trading picked up and became a truly global industry after the launch of the European Union Emissions Trading Scheme (EU ETS) in 2005. At the end of 2011, the global carbon market had a total market value of approximately US$176 billion, of which 84% was accounted for by the EU ETS (World Bank, 2012).

To date, the EU ETS is the largest emissions trading scheme in terms of coverage and traded volumes. Over 11,500 installations, which are responsible for nearly half of Europe's emissions, fall under its scope[1]. The scheme was created to help the European Union cost-effectively meet its emission reduction targets committed under the Kyoto Protocol. The EU ETS is designed as a cap-and-trade programme and is modelled after the U.S. sulphur dioxide (SO_2) emissions trading programme established in 1990. The so-called Acid Rain Program was the first large-scale application of a market-based policy

[1] Directive 2003/87/EC of the European Parliament and f the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Directive 96/61/EC.

instrument to tackle an environmental problem. During the first decade of its existence, SO_2 trading created a liquid market that enabled electricity producers to decrease their emissions. The success of the sulphur market is often seen as evidence that emissions trading is a viable approach to addressing environmental concerns in a cost-efficient manner (for a detailed overview of the history of the sulphur market, see Burtraw and Szambelan, 2009).

In the EU ETS, it is the European Commission that sets the CO_2 cap by issuing permits at the targeted level of emissions to all member states covered by the scheme. Each issued permit - called a European Union Allowance (EUA) – entitles its holder to the right to emit a tonne of carbon dioxide into the atmosphere. The total amount of issued allowances (through free allocation and auctions) across European member states determines their scarcity, and in turn, the price of carbon. Up until 2013, each of the member states was in charge of developing their own National Allocation Plan (NAP) which specifies the total amount of carbon emissions (i.e. the national cap) and the distribution of this total across all regulated installations. The plans are subject to the European Commission's oversight, appraisal and sanction. The severity of the implied reduction targets varies considerably across countries – for example, the United Kingdom has had a consistent deficit of EUAs since the launch of the scheme, while Eastern European countries have enjoyed generous EUA allocations far in excess of their business-as-usual activities.

As will be discussed in detail in Section 3.2.1.1, the majority of regulated installations are issued with carbon allowances for free. Because different companies face different costs of internal abatement, a market-based approach to carbon reduction enables them to choose the best course of action in order to minimize their costs and/or maximize profits. In essence, the free allocation of EUAs resembles a real option granted to the covered company. If the company's cost of carbon reduction exceeds the market price of the allowances, it can choose to use up all of its allocated EUAs and forgo the investment in carbon-efficient equipment. For those companies which can abate internally at a cheaper cost, reduction of emissions by more than what is required will generate a surplus of unused allowances. These excess EUAs can be saved for future use (or in the carbon market's jargon, they can be banked inter-temporally), they can be sold in the market to companies which exceed their emissions limits, or they can be used for speculative trading.

Covered installations can trade EUAs directly with each other (over-the-counter), on electronic exchanges (i.e. secondary markets) or via brokers. The scheme is structured so that highly-polluting installations in sectors which are relatively protected from international competition, such as electricity generation, bear the brunt of emissions reduction. This approach has led to a considerable heterogeneity in the EUA allocations across sectors. Combustion[2] is the only sector which has had a deficit of allowances since the launch of the EU ETS. Trotignon and Debolsc (2008) estimate that allocations to power plants represent over 50% of a country's total allocations on average. The authors also find that more than 90% of the entire allowance shortage in the scheme during the period 2005-2007 was caused by EUA deficits of power plants.

Unlike other conventional markets, the carbon market is a product of environmental policy. Given its fairly short history and its politically-driven nature, the question then arises – is the market actually working? Two aspects need to be addressed – whether the EU ETS

[2] The combustion sector includes power and heat producers, as well as in-house combustion installations of food &beverage companies, pharmaceuticals, etc.

functions efficiently as a financial market and whether it achieves its intended socio-economic results. For the market to be an effective tool of environmental policy, it must provide the necessary incentives to companies to alter their carbon performance. Academic research into this new European carbon market has quickly gained momentum over the past few years. Much of the existing research into the efficiency of the carbon market has focused on the spot-forward parity (e.g. Borak et al., 2006; Uhrig-Homburg and Wagner, 2009), the existence of a single, arbitrage-free carbon price despite the multiple European trading platforms (e.g. Mansanet-Bataller and Pardo, 2008;Boutaba, 2009), and the overall efficiency of the market (e.g. Daskalakis et al., 2008; Montagnoli and de Vries, 2010). Several recent papers have tested the market efficiency hypothesis in an event study framework by looking at market responses to regulatory announcements by the European Commission (e.g. Mansanet-Bataller and Pardo, 2009; Rotfuβ et al., 2009).

With this thesis, I attempt to fill several gaps in the existing carbon literature. While market efficiency is typically defined as asset price behaviour which is consistent with Fama's 1970 Efficient Market Hypothesis (EMH), I interpret efficiency in a broader context. Fama (1970) argues that a market is efficient if prices reflect all available information, so that investors cannot achieve abnormal profits by trading on the basis of information contained in historical prices. In addition to this traditional EMH interpretation, I extend the definition to cover the environmental aspect of the market and argue that the market can be referred to as efficient only if the carbon performance of regulated companies is reflected in their stock prices. Therefore, I proceed with the thesis by examining the informational efficiency of the EU ETS in its completeness – from both a financial market perspective and an environmental perspective. I look at the information content of carbon options, I assess whether investors respond to new information accurately and, finally, I examine whether the carbon performance of companies has implications for their market valuations.

A priori should the carbon market be expected to be efficient? First, carbon permits resemble other financial instruments in that they are entirely fungible across companies and they require no transportation or storage charges. Second, as already highlighted, the allocation of allowances and the emission reduction burden are not distributed equally across all regulated sectors. Even within those sectors which have a net excess of allowances, there are firms with deficits of EUAs and firms with surpluses. Furthermore, demand is additionally affected by unpredictable factors like the weather, the economy, energy prices and innovation in carbon-reducing technologies. As long as there are buyers and sellers of allowances, trading in carbon is ensured and the scheme can be expected to function efficiently from a financial perspective. This implies that for some companies with a deficit of allowances, carbon reduction is, and will continue to be, costlier than the purchase of allowances in the market.

A certain level of inefficiency is natural at the very inception of the scheme as there is uncertainty about the risk premium which should be reflected in underlying spot carbon prices, and the fair pricing of derivatives is complicated by the lack of a sufficiently long spot trading history. However, with the presence of energy trading companies, hedge funds, pension funds and various financial investors on the market, inefficiencies that create money-making opportunities should be quickly arbitraged away. I therefore expect pricing inefficiencies to be resolved early on and carbon permits to be valued fairly, with new information reflected in their prices in a timely and accurate manner. By the same token, I expect all derivative instruments which have the right to emit carbon as an underlying asset (futures and options) to be efficiently priced.

With regard to the efficiency of the market in meeting its environmental objectives, I do not expect that compliance with the EU ETS has led companies to dramatically cut back on their carbon emissions. Generous allocations of free allowances in the early years of the scheme and a slowdown in economic activity following the crisis in 2008 have created a supply of unused EUAs in the system and have distorted the incentives of companies to de-carbonize their operations. Although the market is probably not yet meeting the socially desirable objectives of altering corporate behaviour, I anticipate that carbon performance is at least reflected in the financial performance of companies. As carbon permits represent tradable assets with a quantifiable monetary value, excess allowances (shortages) of EUAs should increase (decrease) the market values of covered companies.

First, I address market efficiency by examining the forecasting accuracy of volatility embedded in carbon options. Since the carbon market is new, and derivatives' trading on emission allowances has only started very recently, carbon options have not yet been extensively studied. The rapid development of the carbon option market does not come as a surprise. Long call positions are a natural hedge for a regulated emitter which emits more than its allocated quota. Similarly, companies with excess allowances can buy put options and lock in a selling price. Market efficiency suggests that, conditional upon the accuracy of the option pricing model, implied volatility should be an unbiased and efficient forecast of future realized volatility (Campbell et al., 1997). Several idiosyncratic aspects of the carbon market could negatively impact the hypothesized relationship. These include the concentration of trading in futures with long maturities, the fairly low liquidity of the market, and the high level of uncertainty inherent in a market conceived as a solution to an environmental problem. To my knowledge, there is no published study yet which examines the hypothesis that carbon option implied volatility is a rational forecast of subsequently realized volatility. In Chapter 2, I provide empirical evidence about the information content of carbon options over the three-year period between January 2008 and December 2010.

Second, I re-examine the ability of market participants to accurately respond to new information about the institutional framework of the EU ETS. The institutional framework is defined as emission caps, the rules for distributing carbon allowances across companies, the linking of the EU ETS to Kyoto projects, and the availability of alternative carbon financial instruments for compliance. Prior literature has examined reactions to announcements about the emission caps over the first two trading periods of the EU ETS and the releases of verified emissions data (e.g. Miclaus et al., 2008; Rotfuβ et al., 2009; Lepone et al., 2011). In addition to these, I study the impact of a wider spectrum of announcements on carbon returns, on the variance of carbon returns and on option implied volatility. I also examine the change in market responsiveness to institutional announcements following the onset of the financial crisis, an issue which has not been addressed so far in the existing literature. In Chapter 3, I provide the empirical evidence on the ability of investors to accurately price in new information in the context of different rules on inter-temporal banking and borrowing of allowances.

Third, I explore the relationship between carbon emissions and financial performance for British and German publicly-traded companies covered by the EU ETS. I establish whether the carbon market conveys value-relevant information to investors. The issue of whether carbon performance is priced in firm valuations is of practical significance for covered companies, investment analysts and policy makers alike. There is a growing body of research on the impact of the scheme on individual sectors and companies but the focus has been on potential losses in competitiveness and reductions in profitability (e.g. Neuhoff et al., 2006; Quirion and Demailly, 2006; Demailly and Quirion, 2008). In Chapter 4, I explore the change in financial performance following repeat disclosures of firm-specific carbon emissions data. I also provide empirical evidence to fill in the gap in the literature on the effectiveness of the scheme as a mechanism for facilitating the move to a low-carbon economy. Environmental effectiveness is evaluated by examining whether covered companies alter their carbon performance and de-carbonize their operations as a result of stock price pressures following emission reports publication. I also try to find evidence of changes in the carbon performance of covered companies as a result of such stock price pressures.

1.2. MAJOR FINDINGS AND CONTRIBUTIONS

In this thesis I provide new evidence on the efficiency of the carbon market and its relevance for the valuation of regulated companies. In Chapter 2, I find that implied volatility is a biased and inefficient forecast of future realized volatility. In Chapter 3, I demonstrate that although market participants react to new information, they are not able to accurately assess the implications of inter-temporal banking and borrowing for carbon prices. I also show that no stable relationship exists between the carbon price and its market fundamentals – the institutional framework, energy variables and extreme weather. In Chapter 4, I report that despite the market's rapid growth and the increasing importance of environmental performance, the EU ETS is not relevant for the financial performance of covered companies. This suggests that, at present, the signal embedded in carbon prices does not stimulate investor action and incentivise companies to transition to low-carbon operations. The findings in these three chapters lead me to conclude that the market is not yet fully informationally efficient.

To begin with, I explore an aspect of market efficiency which has been overlooked so far – the relationship between implied and realized volatility in the carbon market. Although there is substantial work on the information content of options for various financial and non-financial instruments (e.g. Canina and Figlewski, 1993; Fleming, 1998; Szakmary et al., 2003), no published study has yet addressed this issue for the carbon market. I find that implied volatility is highly informative about future volatility despite the prevalence of long-dated futures contracts, the fairly low trading volumes and the high level of regulatory uncertainty in the market. No evidence is found that implied volatility estimates obtained from direct surveys of carbon traders perform better than Black's (1976) classical option pricing model estimates in forecasting future volatility. Implied volatility is shown to be directionally accurate in forecasting future volatility. I do not find evidence to support the hypothesis that implied volatility is unbiased or informationally efficient. Instead, the results demonstrate that historical volatility contains incremental information which is not contained in option prices, especially in predicting volatility over short periods of time. These findings suggest that inefficiencies in the carbon market do exist. Inefficiently priced options leave room for arbitrage strategies and speculation. The findings in Chapter 2 offer a possible explanation for the reported prevalence of speculative volatility-based trading in the market (World Bank, 2010).

Second, I re-examine the impact of institutional and regulatory announcements on the carbon price dynamics in Chapter 3. Compared to earlier works in the area (e.g. Rotfuβ et al., 2009; Lepone et al., 2011) my analysis covers a substantially wider range of announcements. In addition to the traditional supply-related events examined to date (announcements about Phase I and II National Allocation Plans and verification events) I consider a comprehensive set of both supply- and demand-related announcements. This thesis also studies market sensitivity to post-2012 announcements and looks at the impact of these announcements on Phase III carbon futures. I provide new evidence about the impact of institutional announcements on carbon returns and option implied volatility. Using two alternative model specifications (univariate time series analysis and a multifactor model) of the carbon price, I find that market participants react to new information about the institutional construct of the EU ETS but fail to assess the differential impact which the rules on inter-temporal borrowing and banking of allowances have for futures contracts with expirations in different trading periods. I confirm prior findings (Mansanet-Bataller and Pardo, 2009; Lepone et al., 2011) that institutional disclosure does not affect the variance of returns. At the same time, I document statistically significant increases in option implied volatility before scheduled institutional events and a reduction afterwards.

Chapter 3 also differs from prior studies by examining changes in the market responsiveness to institutional announcements before and after the financial crisis. Two different techniques are employed in splitting the dataset into subsamples – a Bai-Perron structural break test as well as a naïve pre-crisis/full-crisis split. I demonstrate that the institutional framework is only a secondary consideration for the carbon price dynamics and institutional announcements explain much less of the variance in carbon returns following the onset of the financial crisis. Even more, the results suggest that after the start of the crisis the relationship between the carbon market and its fundamentals (institutional framework, energy prices and extreme weather) breaks down altogether. These findings may also suggest that the market is not fully efficient yet.

In Chapter 4, I examine the market response of German and British ETS-covered companies to the publication of their actual carbon emissions over the period 2006-2011. To my knowledge, no published study has yet examined stock price reactions of regulated companies to multiple annual compliance events. The contribution of the chapter is two-fold. I add to the growing literature on the interaction between environmental and financial performance and I also contribute to the scant literature on the impact of emissions trading on individual firms. I examine a unique set of hand-collected data on the carbon performance of companies which was not available prior to the launch of the EU ETS. The event study is performed in a Seemingly Unrelated Regressions framework to deal with the issue of event clustering which arises because all companies are affected simultaneously.

I predict that firms which emit more (less) than anticipated by the market and firms which, contrary to market expectations, find themselves short (oversupplied) of carbon allowances should experience substantial negative (positive) price reactions. I find limited evidence that carbon performance matters to investors by reporting statistically significant market responses only for the disclosure of verified emissions during 2008. The observed significant event returns lend some support to the view that investors react to unanticipated changes in the net EUA position of a company rather than unanticipated changes in its level of emissions. Information about the firms' carbon performance is not instantaneously reflected in stock prices, which I attribute to the format of carbon reporting and the time it takes to convert installation-level data into usable firm-level information. I find no proof that the amount of freely allocated allowances and the amount of actual emissions are significant in explaining the observed market reactions. There is some evidence that information in the carbon reports is more important for companies with high carbon-intensive operations.

Fourth, this thesis contributes to the existing body of knowledge by shedding some light on the social utility of the European carbon market. I predict that negative market responses following the publication of actual emissions lead companies to alter their carbon performance. I also predict that the market rewards companies which have reduced the emissions intensity of their operations and punishes companies which continue to emit carbon at increasing rates. No evidence is found to support either of these hypotheses. The lack of stock price pressures associated with the release of carbon emissions data suggests that, in its current state, the EU ETS does not provide regulated companies with enough financial incentives to de-carbonize their activities.

1.3. Thesis design

The three aspects of informational efficiency examined in this thesis are organized as individual chapters. Chapter 2 looks into the information content of carbon options traded on the European Climate Exchange. Chapter 3 examines the ability of market participants to accurately price in new information regarding the institutional framework of the carbon market. The relationship between carbon emissions and financial performance is investigated in Chapter 4. I conclude with a chapter which summarizes the key empirical results, presents the caveats to the analyses and recommends future areas of research.

CHAPTER 2 THE INFORMATION CONTENT OF CARBON OPTIONS

2.1. INTRODUCTION

As the EU ETS is an entirely political creation, regulatory institutions play a key role in shaping the carbon market (Convery, 2009; Knox-Hayes, 2009). In its short history, the market has witnessed several periods of high volatility caused by regulatory uncertainty. For example, in April 2006 the carbon price collapsed when leaked information about the verified emissions for the previous year showed that, contrary to expectations, there would be no scarcity of emission allowances. More recently, in June 2009, evidence was found of fraudulent trading of emission allowances, leading to the temporary suspension of trading activity in Europe's largest spot carbon market, BlueNext. In early 2011, trading of carbon emissions was temporarily halted again after the discovery that hackers had broken into the EU ETS electronic registries and stolen €30 million worth of allowances (Wall Street Journal, 2011). These irregularities prompted the European Commission to take steps to improve the functioning of the EU ETS, including the creation of a single EU registry[3].

Since the launch of the EU ETS in 2005, the range of carbon derivative products available for trading has grown to include futures, forwards and options on futures. Although the majority of transactions are attributed to futures trades, there has been a steady growth in the number of traded option contracts with the value of the EUA-based options estimated at US$14.2 billion as of December 2011 (World Bank, 2012). The increasing liquidity and

3 European Commission, "EU Emissions Trading System - Transition to the Union Registry". Available online at: http://ec.europa.eu/clima/news/articles/news_2011071802_en.htm

volume of trading in the carbon market has attracted many investors to access this emerging asset class. In addition to regulated industrial emitters, carbon trading has become popular with financial institutions and private individuals, hedge funds and insurance companies. While some of these investors may seek the potential portfolio diversification benefits of the new carbon financial instruments or find them suitable as a part of socially responsible investment strategies, many seem to be drawn to the possibility of gains from speculation and the exploitation of market inefficiencies.

In its annual 2010 overview of the state and trends in the carbon market, the World Bank highlighted that “the bulk of activity now comes from volatility and other relative value trades (i.e. financial and technical trades now account for a greater portion of market activity than do trades for compliance purposes)” (World Bank, 2010: p.16). The reported prevalence of speculative volatility-based trading by financial institutions casts some doubt on the efficiency of the carbon market. Assuming the market is efficient and the model used to derive implied volatility is an accurate description of the way in which the market prices options, implied volatility should be an unbiased and efficient forecast of future realized volatility (Campbell et al., 1997). While the empirical literature on the information content of implied volatility is extensive, no published paper has yet examined the relationship between implied and realized volatility in the carbon market. The hypothesis that implied volatility is a rational forecast of subsequently realized volatility has been frequently tested in the literature for a variety of underlying assets, but the results are equivocal and vary across different options markets. This chapter therefore makes a contribution to the literature on the predictive power of implied volatility as well as adding to the scarce studies of carbon options.

Why is forecasting volatility important for the carbon market? The practical applications and benefits of volatility predictions vary across the different market participants. For a company covered by the EU ETS, carbon price volatility carries several costs. Difficulty in forecasting carbon prices delays investments in low-carbon technology. Firms will choose to hold out and get more insight into the potential price path in order to make a more informed decision. Ability to forecast volatility therefore reduces uncertainty and risk aversion. Promoting investments in carbon-reducing technologies is only one of the reasons why predicting volatility is important for regulated installations. Mitigation of cash flow risk is another benefit. Under the rules of the scheme, firms are required to surrender allowances for the emissions they have released in the atmosphere at the end of April each year. If a company knows it will need to buy more allowances in the market in order to achieve compliance, without an ex-ante accurate assessment of price volatility it risks paying too much. Thus, failure to assess volatility properly can leave covered companies with excessive exposure to market fluctuations. Alternatively, market participants can use derivatives to hedge their cash flow risk. Because volatility is a key input in derivatives' valuations, volatility forecasts will aid regulated emitters in assessing whether they are paying a fair price to buy these financial instruments.

Volatility forecasts are critical components for the development of speculative trading strategies and betting on the future volatility by regulated companies and financial investors alike. In their in-depth overview of trade patterns during Phase I of the EU ETS, Trotignon and Delbosc (2008) note that regulated entities known to have excess EUAs still buy and surrender allowances from other installations – a finding which implies that either managers of these companies find it difficult to assess the amount of the EUAs needed (which is unlikely given their ability to borrow permits inter-temporally) or that regulated companies engage in speculative trading of allowances. Price volatility creates an opportunity for speculation based on valuations – assets can be bought cheap and sold when overpriced. Furthermore, mispriced options can be identified on the basis of volatility forecasts. For financial investors in the carbon market, aside from being critical in asset valuations volatility estimates are also central to asset allocation and risk management decisions. For instance, portfolio allocations often rely on Markowitz risk-return optimization where volatility is a key input. Similarly, risk mitigation strategies generally use variance-covariance matrices between different asset classes in order to assess maximum possible losses.

This chapter examines the information content of volatility implied by options on the carbon futures traded on the European Climate Exchange (ECX), Europe's largest carbon derivatives trading platform, over the period January 2008 – December 2010. Two distinct features of the carbon market compared to other, more traditional, options and futures markets are the prevalence of long-dated (December) contracts and the uncertainty surrounding the carbon market due to its politically-driven nature. Both of these features can potentially have a negative impact on the information content of the option prices.

The following empirical results are obtained. First, implied volatility is highly informative about the future variance of returns despite the long maturity cycle of the carbon options and their still relatively infrequent trading. Second, directly surveyed implied volatility does not appear to be a better forecast of future volatility than Black implied volatility. Third, despite its significant predictive power, implied volatility is a biased forecast of future volatility over the remaining life of the options as well as over shorter forecasting horizons. Fourth, I find no evidence to support the hypothesis of informational efficiency and conclude that implied volatility is an inefficient estimator of future volatility. Last, the results indicate that forecasts based on implied volatility have statistically significant power in predicting future volatility changes.

The rest of the chapter is organized as follows. Section 2.2 summarizes existing empirical research on the information content of implied volatility. The methodology and data used in this chapter are presented in Sections 2.3 and 2.4, respectively. Section 2.5 discusses the results, and Section 2.6 concludes.

2.2. PRIOR RESEARCH

Since the carbon market is new, and derivatives' trading on emission allowances has only started very recently, carbon options have not yet been extensively studied. Much of the existing research about this market is focused on the spot price dynamics of emission allowances (Paolella and Taschini, 2008; Benz and Trück, 2009; Daskalakis et al., 2009) on spot-forward parity (Borak et al., 2006; Uhrig-Homburg and Wagner, 2009) the ability of historic volatility data to forecast realized volatility (Chevallier and Sevi, 2011; Isenegger and von Wys, 2010) the impact of the introduction of carbon options in 2006 on the volatility of carbon futures returns (Chevallier et al., 2009b) or the overall efficiency of the market (Mansanet-Bataller and Pardo, 2008; Boutaba, 2009; Montagnoli and de Vries, 2010). The aim of this chapter is to fill a gap in the literature by analysing the implied volatility of carbon options.

Implied volatility can be defined as the volatility for which the current market price of an option equals the theoretical option price estimated according to a specific option pricing model. The use of implied volatility as a forecast of the expected variance of returns of the underlying asset can be justified if two assumptions are made. First, markets are assumed to be efficient so that all publicly available information is incorporated in option prices. Second, the option pricing model used to derive implied volatility correctly captures the mechanism used by the market in pricing the option. If the market values options in a manner different from that suggested by the model used to obtain implied volatility, volatility estimates will be imprecise and will differ from the market's true expectations (Campbell et al., 1997). This is referred to as model misspecification and leads to inaccurate inferences about the underlying volatility dynamics and invalid conclusions about the information content of implied volatility.

A common approach in the existing body of research is to derive implied volatility from the Black (1976) model for options on futures. At-the-money options are considered the most robust source for implied volatility estimations due to their liquid trading and high sensitivity to the variance parameter (Poon and Granger, 2003). When at-the-money options are not available, studies have used the most actively traded options (Kumar, 2008), nearest-to-the-money or nearest-to-expiration options (Canina and Figlewski, 1993). Different weighting schemes for nearest-to-the-money proxies of implied volatility exist in the literature (see Ederington and Guan, 2002 for a comprehensive overview) with the results suggesting that the choice of weighting structure is not of primary importance.

The conventional approach to testing the predictive power of implied volatility in terms of unbiasedness and efficiency is to estimate an Ordinary Least Squares (OLS) regression of ex-post realized volatility on implied volatility and alternative historical information-based predictions. If implied volatility is an unbiased estimator, ex-post realized volatility should equal implied volatility plus a white noise disturbance term. To meet the efficiency criterion, implied volatility should encompass all information contained in historical volatility. The downside to such an econometric analysis of the predictive power of implied and historical volatility is that conclusions are based on how closely the sample data fits the selected models for measuring volatility. The quality of the prediction is based entirely on the coefficient of determination from the regression equation. Forecasts resulting in a high coefficient of determination and low standard errors are interpreted as good estimators but they only reflect the sample data, which may differ from the true population parameters. Thus, the predictive power of the explanatory variables might be strongly exaggerated (Brooks, 2008). Estimating the volatility parameter is additionally affected by the choice of a sampling methodology, the time interval over which returns are measured and the length of the time period under investigation.

Early studies on the information content of implied volatility generally conclude that it outperforms historical volatility (Latane and Rendleman, 1976; Chiras and Manaster, 1978; Schmalensee and Trippi, 1978; Beckers, 1981). Following these studies, research has focused on refining the methodology by increasing sample sizes, taking into account time series properties of the data, dividend payments and transaction costs. Subsequent researchers also expanded the conditioning set of information available to investors to include more sophisticated forecasts based on autoregressive time series models – ARCH, GARCH and various extensions of these.

The conclusion from later research suggests that implied volatility is a biased yet efficient forecast, but the results are far from unanimous. For example, Canina and Figlewski (1993) find virtually no correlation between ex-post realized volatility and volatility implied by the options on the S&P 100 index. The authors attribute the biasedness and inefficiency of implied volatility forecasts to the fact that classical option pricing models fail to incorporate many factors important to investors in the real world such as liquidity, correlations between different indexes and investors' preferences for specific payoff profiles. In a later study, Christensen and Prabhala (1998) employ a non-overlapping sampling framework over the same period as in Canina and Figlewski (1993) and report that S&P 100 implied volatility is both unbiased and efficient, subsuming all information contained in historical data. Analysing a different time period, Fleming (1998) concludes that volatility implied by the S&P 100 index options is an efficient but biased estimator which tends to considerably exaggerate ex-post realized volatility.

Corrado and Miller (2005) investigate the predictive power of volatility implied by the Chicago Board Options Exchange volatility indexes based on the S&P 100, S&P 500 and NASDAQ stock indexes – VXO, VIX and VXN, respectively. VXO and VIX implied volatility is demonstrated to be an efficient estimator of future volatility, subsuming all information contained in naïve and GARCH-based historical volatility. Examining intraday returns for the S&P 500 index over an almost identical time period to that of Corrado and Miller (2005), Becker et al. (2006) confirm the highly informative power of VIX implied volatility but conclude that it is an inefficient forecast of future volatility.

Analyses of the implied volatility embedded in equity options from different countries are also provided by Li and Yang (2009) and Frijns et al. (2010) for Australia, Kumar (2008) for India and Moraux et al. (1999) for France. Szakmary et al. (2003) study the predictive power of option implied volatility by examining 35 futures markets including currencies, interest rates, and various non-financial products in addition to equities. For the majority of the markets examined, the authors find that implied volatility is a biased but efficient estimator of ex-post realized volatility.

Mixed results as to the information content of implied volatility are observed in the literature on commodities and foreign exchange rates as well. Some authors maintain that implied volatility is a biased estimator but that it subsumes all information contained in historical time-series data (Jorion (1995) on foreign exchange rates; Manfredo and Sanders (2004) on agricultural commodities; Bakanova (2010) on the crude oil market), while others demonstrate that GARCH models dominate implied volatility forecasts (Agnolucci (2009) on the crude oil market; Martens and Zein (2004) on the crude oil and foreign exchange markets; Neely (2004) on gold futures). An unobserved time-varying volatility risk premium is the most common explanation for the systematic bias of implied volatility in forecasting future variance of returns (Poteshman 2000; Bandi and Perron, 2006; Neely, 2009).

Recent advances in the field have focused on improving investors' understanding of the latent volatility dynamics by employing high frequency data (Andersen and Bollerslev, 1998; Blair et al., 2001) and modelling volatility as a long-memory process (Li, 2002; Andersen et al., 2003; Neely, 2004; Bandi and Perron, 2006). Despite the improved performance of time series-based forecasts when intraday returns are employed, Blair et al. (2001) find that implied volatility still outperforms alternative forecasts.

2.3. METHODOLOGY

2.3.1. PREDICTIVE POWER OF IMPLIED VOLATILITY

The hypothesis that implied volatility contains information about ex-post realized volatility and can be used as a forecast of how volatile carbon prices can be is tested by estimating an OLS regression of the form:

$$\sigma_{realized,t} = \alpha + \beta\sigma_{implied,t} + \varepsilon_t \qquad (1)$$

where $\sigma_{realized,t}$ is the volatility realized over the remaining life of the options.

If option implied volatility contains information about future volatility, the regression coefficient β will be statistically different from zero. In addition, if implied volatility is an unbiased predictor of realized volatility, the regression coefficient will be 1 and the intercept will not be statistically significant from zero. In other words, it is a test of the joint hypothesis that $\alpha=0$ and $\beta=1$, referred to as the "rationality test" by Canina and Figlewski (1993).

Due to the use of overlapping samples, the forecast error is not white noise, but rather a moving average. For example, when volatility is measured on a daily basis and volatility forecasts are made for 10 days ahead, the error term will follow a ninth-order moving average process. OLS is still applicable under such conditions but Newey-West robust standard errors are employed to account for the serially correlated error terms. Therefore, all regression results reported in this chapter rely on Newey-West standard errors which adjust for both heteroscedasticity and autocorrelation.

To capture the effect of time to maturity on implied volatility as a predictor of future variance, five dummy variables are introduced in the OLS regression equation, defined as follows:

D_1=1 if the option has ≤1 month (approximated by 22 trading days) until expiration, 0 otherwise

D_2=1 if the option has > 1 and ≤2 months (between 23 and 44 trading days) until expiration, 0 otherwise

D_3=1 if the option has > 2 and ≤4 months (between 45 and 88 trading days) until expiration, 0 otherwise

D_4=1 if the option has > 4 and ≤6 months (between 89 and 132 trading days) until expiration, 0 otherwise

D_5=1 if the option has > 6 and ≤9 months (between 133 and 198 trading days) until expiration, 0 otherwise

In addition, five interactive terms are created by multiplying the dummy variables by the implied volatility time series ($D_1\sigma_{imp,t}$, $D_2\sigma_{imp,t}$, $D_3\sigma_{imp,t}$, $D_4\sigma_{imp,t}$, and $D_5\sigma_{imp,t}$). The new regression equation takes the form:

$$\sigma_{realized,i,t} = \alpha + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_5 + \gamma_1 D_1\sigma_{imp,t} + \gamma_2 D_2\sigma_{imp,t} + \gamma_3 D_3\sigma_{imp,t} + \gamma_4 D_4\sigma_{imp,t} + \gamma_5 D_5\sigma_{imp,t} + \delta\sigma_{imp,t} + \varepsilon_t \qquad (2)$$

where i signifies the alternative specifications of ex-post realized volatility employed in this chapter.

2.3.2. Informational efficiency of implied volatility

Following prior research in the area of predicting financial volatility (Fleming, 1998; Christensen and Prabhala, 1998), I examine the efficiency of the implied volatility forecast.

In order to test the efficiency hypothesis, realized volatility is regressed against both implied and historical information-based forecasts. That is,

$$\sigma_{realized,t} = \alpha + \beta_1 \sigma_{historical,t-1} + \beta_2 \sigma_{implied,t} + \varepsilon_t \quad (3)$$

For option implied volatility to be an informationally efficient forecast, it should incorporate all publicly available information. Adding historical volatility as al regressor should result in no observed performance improvement. The slope regression coefficient of historical volatility is expected to remain statistically indistinguishable from zero. Deviation from the results $\alpha=0, \beta_1=0, \beta_2=1$ is evidence of bias and inefficiency.

2.3.3. Directional accuracy of implied volatility forecasts

To assess the directional accuracy of implied volatility forecasts, this chapter employs the methodology of Levich (1979). As noted by the author, useful forecasts are the ones that lead you to be "on the right side of the market" (Levich, 2001: p. 275). Following his approach, the directional accuracy of implied volatility from carbon options is examined using a binomial test. The percentage of correct forecasts of future volatility increases and decreases is tested individually. Under the null hypothesis:

H_0: $p = 0.5$ where p is the percentage of successful forecasts and is expected to be 50% if implied volatility is not superior in forecasting the future direction of volatility than a simple guess

H_1: $p > 0.5$

The standard deviation of p under the null hypothesis is therefore $\sqrt{p(1-p)/n}$, where *n* is the total number of forecasts.

2.4. DATA

Options on carbon futures were formally launched in October 2006; the initial learning phase of the EU ETS ended in December 2007 and the scheme entered into its second phase on January 1st, 2008. The analysis focuses on futures which expire in the second phase only. The ECX presently trades options written on two underlying products: European Union Allowances (EUAs) and Certified Emission Reduction units (CERs). The chapter focuses on options with underlying allowances because of their higher liquidity and transaction volume. These options currently trade on a quarterly expiry, following a March-June-September-December cycle. The underlying contract is the December future of the relevant year, with most of the liquidity concentrated in options with a December expiry. Over the sample period, the nearest-to-maturity non-December option contracts represent merely 0.23% of the trading volume in the closest December contract.

The available data consist of daily settlement prices as well as high, low, opening and closing prices for all relevant ICE ECX EUA futures contracts. Given the concentration of liquidity in options with December expirations, only these are kept in the sample. Moreover, for a given year the sample of data is constructed to include only options with the nearest expiration. That is, the set of observations for 2009, for example, contains the December options for the futures contract expiring in 2009. This was done to limit the life-cycle of carbon options covered by the analysis to a maximum of one year. The futures contracts with nearest expiration make up the majority of the exchange-traded volume throughout the year: 69% in 2008, 70% in 2009 and 69% in 2010. This leads to a total of 714 daily settlement prices of ICE ECX EUA futures contracts covering the period 02/01/2008 – 08/12/2010. All data were taken directly from the official website of the

ECX, the InterContinental Exchange (www.theice.com).

The settlement prices of the futures during the time period covered by this study are converted into continuously compounded rates of return, $r_t = ln\,(\frac{P_t}{P_{t-1}})$. The descriptive statistics in Table 2.1 in reveal a skewness of 0.03, indicating a fairly symmetric distribution of returns. The excess kurtosis, however, implies fat tails and suggests that the shape of the data does not follow a Gaussian distribution. The Jarque-Bera statistic provides evidence that the null hypothesis of normally distributed residuals can be rejected with nearly 100% confidence.

Table 2.1 Descriptive statistics
This table reports the descriptive statistics of the log-returns for the ICE ECX EUA futures contracts and the realized (RV) and implied (IV) volatility time series over the period 02/01/2008 – 08/12/2010. The volatility of the underlying futures contract realized until the expiration of the option written on the given contracts is measured by squared returns, Parkinson's and Rogers and Satchell's variance estimators. Implied volatility reported by the European Climate Exchange and Black (1976) implied volatility are reported as well.

	Log returns	Squared Returns RV	Parkinson RV	Rogers and Satchell RV	ECX Implied Volatility	Black Implied Volatility
Mean	-0.06	33.83	33.06	32.91	46.17	45.30
Median	0.00	34.20	33.14	31.95	47.15	45.97
Maximum	11.37	69.28	53.31	59.31	67.88	67.40
Minimum	-9.43	0.10	17.34	17.52	27.97	26.44
St. Deviation	2.43	11.28	10.00	10.53	9.85	9.71
Skewness	0.03	0.08	0.09	0.17	0.00	0.00
Kurtosis	5.12	2.62	1.85	1.82	2.15	2.20
Jarque-Bera	133.74	3.99	31.87	35.83	17.22	15.23
Probability	0.00	0.14	0.00	0.00	0.00	0.00
Observations	713	569	569	569	569	569

2.4.1. Realized volatility

One of the objectives of this chapter is to examine how the measurement of realized volatility influences the relationship between implied and realized volatility. Realized volatility is calculated from the time series data of ECX EUA futures prices over the remaining life of the options written on these contracts. Three alternative specifications of realized volatility are used.

The first measure of realized volatility is squared daily returns, the most widely used definition in the literature. Returns are calculated over a one-day interval on a continuously compounded basis, as recommended by Campbell et al. (1997). This chapter follows Figlewski (2004) and Hull (2006) in assuming a mean daily return of zero. This approach is suitable given the small set of observations and the high probability that the sample mean is an imprecise estimate of the true population mean μ. The expression for realized volatility estimated from daily settlement prices of the ECX EUA futures contracts is as follows:

$$\sigma_t^{(n)} = \sqrt{\frac{252}{n} \sum_{i=0}^{n} r_{t+i}^2} \tag{4}$$

where n is the number of trading days left till expiration of the option.

Since intraday information about the prices of carbon allowances is not available, I employ two extreme value volatility indicators which have been found useful in capturing the price evolution of the underlying asset in the absence of high-frequency data (Fleming, 1998; Bakanova, 2010). These are Parkinson's (1980) and Rogers and Satchell's (1991) volatility estimators. Parkinson (1980) demonstrates that an estimate based on the high and low prices for the day is superior in calculating volatility than simply squaring daily returns. He operates under the common assumption that returns follow a geometric Brownian motion and implicitly assumes that such motion is not characterized by a drift. Rogers and Satchell's (1991) estimator includes opening and closing prices in addition to high/low prices to capture any jumps during non-trading times. Rogers and Satchell (1991) relax the assumption of a driftless random walk assumed by Parkinson (1980).

Following Parkinson (1980), the second measure of realized volatility is defined as follows:

$$\sigma_t^2 = \frac{1}{4ln2}[ln\,(high)_t - ln(low)_t]^2 \tag{5}$$

Rogers and Satchell's (1991) variance estimator, and respectively my third measurement of realized volatility, is calculated as follows:

$$\sigma_t^2 = ln\left(\frac{high_t}{open_t}\right) ln\left(\frac{high_t}{close_t}\right) + ln\,\left(\frac{low_t}{open_t}\right) ln\,\left(\frac{low_t}{close_t}\right) \tag{6}$$

In annualizing the standard deviation, daily estimates are multiplied by the square root of 252 trading days per year, following the convention in the derivatives market (Hull, 2006). In order to get the annualized volatility over the remaining *n* trading days until the expiration of the option for the extreme-value estimators, the following adjustment is made:

$$\sigma_t^{(n)} = \sqrt{\frac{252}{n}\sum_{i=0}^{n}\sigma_{t+i}^2}$$

where σ_{t+i}^2 is the variance calculated by Equations 5 and 6.

Theoretically, Rogers and Satchell's definition of volatility should dominate Parkinson's estimate because it relaxes the assumption of a driftless random walk and includes opening and closing prices in addition to high/low prices to capture any jumps during non-trading times. My expectation is that the third measurement of realized volatility will lead to the most accurate representation of the volatility dynamics and, therefore, that implied volatility will have higher forecasting power. The descriptive statistics of the three realized volatility time series are summarized in Table 2.1.

2.4.2. Historical volatility-based forecasts

A common assumption in empirical finance is that conditional volatility follows a GARCH model. In this chapter I also choose to model historical volatility by estimating a GARCH (1,1) model in the following way:

$$r_t = \mu + e_t, \tag{7}$$

where $e_t \sim N(0, \sigma_t^2)$ is a white noise, stationary process, and

$$\sigma_t^2 = \alpha_0 + \alpha_1 e_{t-1}^2 + \beta_1 \sigma_{t-1}^2 \tag{8}$$

where $\alpha_0 > 0$, α_1, $\beta_1 \geq 0$ and $\alpha_1 + \beta_1 < 1$.

The non-negativity of all regression coefficients is a necessary condition to ensure a positive variance and the sum of $\alpha_1 + \beta_1$ (commonly known as a persistence factor) less than unity ensures the stationarity of the process (Brooks, 2008). To confirm that the selected model is appropriate for the log-return EUA time series, I test for the presence of GARCH effects over the time period covered by the analysis (January 2008 – December 2010) and I check for model misspecification. The ARCH-LM statistic of 138.9 is significant even at the 1% level, confirming the presence of ARCH effects in the EUA log-returns. Both the ARCH and GARCH coefficients (0.09 and 0.88, respectively) are statistically significant and their sum adds up to 0.98, suggesting that shocks to volatility have a strong and persistent impact on the conditional variance of carbon prices[4]. Because the standard residuals do not exhibit a normal

[4] A test has been performed to confirm that the sum of the ARCH and GARCH effects is statistically different from unity i.e. that the shocks to volatility are not merely persistent but constant. The results reject the existence of an Integrated GARCH model.

conditional distribution, Bollerslev-Wooldridge heteroscedasticity consistent robust standard errors are estimated through a Quasi Maximum Likelihood method (QML). The Q-statistics and correlograms of the autocorrelations and partial autocorrelations demonstrate that the GARCH (1,1) standardized residuals are distributed independently, both linearly and non-linearly (none of the Q-statistics for the standardized and squared standardized residuals are significant at the 1% level). These tests imply that a GARCH (1,1) model with robust standard errors is properly specified.

It is worth noting that a standard GARCH (1, 1) model implicitly assumes symmetric volatility responses to bad and good news of equal magnitude. A leverage effect, whereby volatility responds more strongly to negative news, has been well-documented in the equity literature. Asymmetric models like the EGARCH allow good and bad news of equal size to impact conditional volatility differently. I confirm that such an asymmetric reaction exists in the EUA log-return series (estimating an EGARCH model, I find that the asymmetry coefficient of -0.078 is statistically significant at the 1% level) but I still prefer to model historical volatility as a standard GARCH (1, 1) process. The relative out-of-sample forecasting accuracy of different volatility models has been examined in numerous studies. Awartani and Corradi (2005) find that while asymmetric GARCH models perform better than a simple GARCH (1, 1) in a one-step ahead forecast, the former perform only marginally better in longer forecast horizons. Ederington and Guan (2005) report that out-of-sample GARCH (1, 1) and EGARCH forecasts are equally accurate. Nevertheless, s future improvement to the analysis presented in this chapter would be to supplement the symmetric GARCH (1, 1) forecasts with forecasts based on models which explicitly account for asymmetric responses in volatility.

In terms of applying the GARCH (1, 1) model, estimation of a rolling GARCH on a recursive window of observations was impossible due to multiple violations of the non-negativity constraints noted above. Therefore, the GARCH parameters were estimated only thrice. The 257 daily observations from January 3, 2007 until December 31, 2007 were used to derive the parameters of the GARCH process used for forecasts in 2008. At the end of 2008, the GARCH model was re-estimated and parameters were extracted from the period from January 3, 2007 up until December 3, 2008, resulting in a total of 495 daily observations. Forecasts in 2010 were based on GARCH parameters estimated from the 474 observations spanning the period January 2, 2008 – December 2, 2009. The GARCH parameters are reported in Table 2.2. The fairly stable GARCH coefficients derived from the three estimations suggest that there were no dramatic changes to the pattern of conditional volatility over the period under examination.

Table 2.2 GARCH specifications

The table reports the GARCH parameters used in forecasting over the sample period 02/01/2008 – 08/12/2010. The 257 daily observations from 03/01/2007 until 31/12/2007 are used to derive the parameters of the GARCH process used for out-of-sample forecasts in 2008. At the end of 2008, the GARCH model is re-estimated and parameters are extracted from the period 03/01/2007 – 03/12/2008, for a total of 495 daily observations. Forecasts in 2010 are based on GARCH parameters estimated from the 474 observations spanning the period 02/01/2008-02/12/2009. The associated p-values are reported in parentheses.

	2008 GARCH forecasts	**2009 GARCH forecasts**	**2010 GARCH forecasts**
Constant	0.1231	0.3117	0.262
	(0.163)	(0.004)	(0.031)
Alpha	0.1044	0.106	0.0991
	(0.000)	(0.000)	(0.001)
Beta	0.8718	0.8414	0.8638
	(0.000)	(0.000)	(0.000)

Following Brooks (2008), on day *t*, forecasts about volatility *m* days ahead were derived from the formula:

$$\hat{\sigma}_{m+t}^2 = \sigma^2 + (\alpha_1 + \beta_1)^m(\sigma_t^2 - \sigma^2) \qquad (9)$$

where $\sigma^2 = \frac{\alpha_0}{1-(\alpha_1+\beta_1)}$ is the unconditional variance of returns and σ_t^2 is the daily squared return on day *t*. Since this is a forecast for time *t* + *m* in the future, volatility realized over the following *m* days is calculated as the average of the individual forecasts for the days included. All volatilities are annualized.

2.4.3. IMPLIED VOLATILITY

Due to the relative immaturity of the carbon derivatives market, there are still some days when options on the ICE ECX EUA futures contracts do not trade. As missing observations could potentially introduce bias in the analysis (Neely, 2004, 2009), the days with no traded observations were carefully examined, but no systematic difference was found between realized volatility on days with missing implied volatility and days when both volatilities were observable. All regression analysis assumes that the unobserved variables are randomly distributed and do not bias the estimates.

As the information content of implied volatility depends upon model specification, two measures of implied volatility are employed in this chapter. The first is the implied volatility obtained from the Black (1976) model and the second is the implied volatility directly reported by the European Climate Exchange. The predictive power of implied volatility computed under these different approaches is then compared.

According to the Black (1976) model, the prices of European call and put options on futures can be found using the following formulae:

$$c = e^{-rT}[FN(d_1) - KN(d_2)] \tag{10}$$

$$p = e^{-rT}[KN(-d_2) - FN(-d_1)] \tag{11}$$

where *c (p)* is the price of a call (put) option, *K* is the exercise price; *T* is the time until expiration measured in years; *r* is the risk-free continuously compounded discount rate and *F* is the price of the underlying futures contract. In addition,

$d_1 = \frac{ln(F/K)+(\sigma^2/2)T}{\sigma\sqrt{T}}$ and $d_2 = d_1 - \sigma\sqrt{T}$

All options with moneyness outside of the 0.5 – 1.5 range are removed as these observations could potentially be inaccurate and characterized by very low liquidity. The risk-free rates are the annualized Euro LIBOR rates, obtained from Thomson One Banker. Data from the last five trading days prior to option expiration is also discarded to prevent possible huge jumps in implied volatility that might distort the underlying relationships. The number of observations was reduced to 576 after non-trading days were removed from the sample.

The implied volatility reported by the ECX is set through two surveys of market participants[5]. The first survey is conducted on a daily basis and inquires about participants' views of the implied volatility of the at-the-money strike options for all traded futures contracts. The second survey is conducted every Wednesday and aims to reflect the market sentiment over the settlement window for futures contracts of various maturities. It models the at-the-money smile/skew by explicitly taking into account the market participants' estimates of the 10%/25%/40%/50%/40%/25%/10% delta strikes. The resulting shape of the volatility smile for each maturity is maintained for a week, until the next survey, while the at-the-money volatility is collected on a daily basis and moves up and down with these

[5] A description of the ECX methodology used in deriving implied volatility was obtained via personal communication with the London headquarters.

changes. There are a total of 582 observations for which ECX-implied volatility is available for carbon options traded over the period January 2, 2008 – December 8, 2010. Since the ECX-reported implied volatility directly presents the expectations of the market participants about future variance of returns, it should theoretically minimize model misspecification error. My hypothesis is that this model-free measure will have greater predictive power than the Black (1976) model.

Preliminary analysis of the ECX and Black implied volatility time series points to a strong association between the two measurements. The correlation coefficient is 0.994, a finding which may be explained by the fact that market participants rely heavily on classical option pricing models like the Black (1976) model in estimating fair value. The less than unity correlation between the two measures of implied volatility might stem from the fact that the ECX reports the traders' assessment of the implied volatility of the at-the-money options, while estimates of Black implied volatility are obtained from nearest-the-money options.

2.5. Empirical analysis

2.5.1. Predictive power of implied volatility

The Augmented Dickey-Fuller test is used to confirm the lack of unit root for all five volatility series (three series of realized volatility measures and two implied volatility series). In the absence of non-stationarity, the hypothesis that implied volatility contains information about ex-post realized volatility is tested by estimating Equation 1. The results are summarized in Table 2.3. The implied volatility reported by the ECX is used in deriving the results reported in Panel A, while the estimations in Panel B are based on the Black implied volatility.

Table 2.3 Efficiency and unbiasedness of option-implied volatility as a forecast of volatility
The table reports the results of Equation 1. Realized volatility (*RV)* is calculated on a daily basis as the variance of returns realized over the days remaining until option expiry. Daily volatility is proxied by squared daily returns, Parkinson's and Rogers and Satchell's variance estimators. Newey-West standard errors are used in deriving the significance of the regression coefficients. P-values of the test β=0 are reported in parentheses.

	Intercept	**Implied volatility**	**Adj. R-squared**	**Obs.**
Panel A: Implied volatility is published by the ECX				
Squared Returns RV	-2.946	0.797	48.3%	582
	(0.357)	(0.000)		
Parkinson RV	-2.110	0.761	56.3%	582
	(0.337)	(0.000)		
Rogers and Satchell RV	-3.687	0.793	54.3%	582
	(0.109)	(0.000)		
Panel B: Implied volatility is derived from the Black (1976) model				
Squared Returns RV	-1.562	0.781	45.6%	576
	(0.619)	(0.000)		
Parkinson RV	-1.19	0.756	54.3%	576
	(0.587)	(0.000)		
Rogers and Satchell RV	-2.456	0.78	52%	576
	(0.267)	(0.000)		

Panel A demonstrates that implied volatility is highly significant for all three measures of ex-post volatility. As anticipated, the adjusted R-squared is higher for the range-based estimators relative to squared returns and peaks at over 56% for Parkinson's measure. In line with the rationality hypothesis of Canina and Figlewski (1993), the intercept of the regression equation is statistically indistinguishable from zero. However, the regression coefficient of implied volatility is consistently below one, with values between 0.76 – 0.8. The Wald test rejects the joint hypothesis that $\alpha=0$ and $\beta=1$ for all three alternative definitions of realized volatility (F-statistics for the squared daily returns, Parkinson's and Rogers and Satchell's estimators are respectively 149.3, 247 and 281.2). This suggests that while highly informative, the ECX-reported implied volatility is a biased forecast of the volatility realized by the underlying futures over the remaining life of the option.

The results reported in Panel B lead to qualitatively and quantitatively identical conclusions, as expected given the high correlation between the two implied volatility measures. Implied volatility is a highly informative but biased forecast of future variance of returns, as evidenced by the failure to accept the joint hypothesis of $\alpha=0$ and $\beta=1$ (F-statistics for the squared daily returns and Parkinson's and Rogers and Satchell's estimators are respectively 124.7, 208.1 and 185.3). The high coefficient of determination suggests that despite being a biased forecast, Black implied volatility can explain a substantial portion of ex-post realized volatility – up to 54% when Parkinson's estimator is used.

To test for the time to maturity effect in the ability of implied volatility to predict ex-post realized volatility, Equation 2 is estimated. Panel A of Table 2.4 presents the results using the ECX-reported estimate of implied volatility while Panel B uses volatility derived from the Black (1976) model. The significance of implied volatility over the individual periods identified by the dummy variables is established by testing the hypothesis that $\gamma_i + \delta=0$ for i=1, 2, 3, 4 and 5. The ($\gamma_i + \delta$) slope coefficients for all five periods are statistically different from zero for both the ECX and Black implied volatilities, regardless of which realized volatility measure is employed.

An interesting observation from Table 2.4 is that the regression coefficients of the interactive terms $D\gamma_i$ decline in value as the option maturity increases. This is very intuitive as the longer the remaining life of the option, the less information will be contained in the volatility implied by the option's price. Conversely, the closer the option is to expiration and the less uncertainty there is the more important option implied volatility becomes in explaining future variance of returns. The Wald tests reject the joint hypothesis of insignificant intercept and implied volatility regression coefficient of unity ($\alpha=0$, $\gamma_i+\delta=1$) for all five periods over which volatility is examined (F-statistics range from 5.8 to 68.9 for

Table 2.4 Time to maturity effect in the ability of implied volatility to predict ex-post realized volatility

This table reports the results of Equation 2 over the period 02/01/2008 – 08/12/2010. Realized volatility (RV) is proxied by squared daily returns, Parkinson's and Rogers and Satchell's variance estimators. D_i is a binary variable which takes on values of 1 when the remaining life until the option's expiration falls within a certain range; and 0, otherwise. D_1 equals 1 for options with 1 month or less till expiration; D_2 – between 1 and 2 months until expiry; D_3 – between 2 and 4 months until expiry; D_4 – between 4 and 6 months until expiry; and finally, D_5 – between 6 and 9 months until expiry. Additionally, five interactive terms $D_i*\sigma_{imp,t}$ are created by multiplying the binary variable D_i by the implied volatility time series. P-values are reported in parentheses.

	Intercept	D_1	D_2	D_3	D_4	D_5	$D_1\sigma_{imp}$	$D_2\sigma_{imp}$	$D_3\sigma_{imp}$	$D_4\sigma_{imp}$	$D_5\sigma_{imp}$	σ_{imp}	Adj. R2	Obs.
Panel A: Implied volatility is published by the ECX														
Squared Returns RV	-16.82	-26.67	0.20	6.54	17.41	32.33	0.62	0.09	-0.10	-0.35	-0.69	1.07	61.8%	582
	(0.00)	(0.00)	(0.78)	(0.61)	(0.05)	(0.00)	(0.00)	(0.48)	(0.78)	(0.09)	(0.00)	(0.00)		
Parkinson RV	-22.75	6.85	13.74	17.50	23.96	32.90	-0.09	-0.23	-0.37	-0.50	-0.69	1.18	62.5%	582
	(0.00)	(0.17)	(0.03)	(0.03)	(0.00)	(0.00)	(0.39)	(0.16)	(0.05)	(0.00)	(0.00)	(0.00)		
Rogers and Satchell RV	-25.48	7.24	17.69	21.31	24.82	33.39	-0.08	-0.31	-0.46	-0.52	-0.70	1.24	60%	582
	(0.00)	(0.16)	(0.01)	(0.01)	(0.00)	(0.00)	(0.46)	(0.08)	(0.02)	(0.00)	(0.00)	(0.00)		
Panel B: Implied volatility is derived from the Black (1976) model														
Squared Returns RV	-16.63	-30.50	0.31	6.77	17.65	32.09	0.82	0.11	-0.10	-0.36	-0.70	1.08	60.4%	576
	(0.00)	(0.00)	(0.97)	(0.47)	(0.02)	(0.00)	(0.00)	(0.58)	(0.67)	(0.05)	(0.00)	(0.00)		
Parkinson RV	-22.47	5.64	13.76	17.59	24.06	32.68	-0.01	-0.22	-0.38	-0.51	-0.70	1.19	61.2%	576
	(0.00)	(0.27)	(0.03)	(0.03)	(0.00)	(0.00)	(0.95)	(0.20)	(0.05)	(0.00)	(0.00)	(0.00)		
Rogers and Satchell RV	-25.23	8.43	17.73	21.45	24.92	33.19	-0.05	-0.30	-0.46	-0.53	-0.71	1.25	58.1%	576
	(0.00)	(0.12)	(0.01)	(0.01)	(0.00)	(0.00)	(0.66)	(0.10)	(0.02)	(0.00)	(0.00)	(0.00)		

both the ECX and Black implied volatilities).

Based on the results from Tables 2.3 and 2.4, I conclude that implied volatility has high predictive power, despite the long maturity cycle of carbon options. Contrary to Fleming (1998) and Li (2002) who find that implied volatility tends to forecast shorter-term ex-post volatility only, I observe that for the carbon market implied volatility can be used as a forecast for horizons of up to one year ahead. Although most of the prior literature is focused on options with a maturity of one month, Li and Yang (2009) conduct a study on the Australian Stock Market where options also have a relatively long maturity cycle of 6 months. In line with the findings in this chapter, they report that despite the longer maturity, implied volatility remains informative about future volatility. The coefficient of determination found by Li and Yang (2009), however, is about half the size of that reported in Table 2.3. A possible explanation of the higher R-squared obtained in the carbon analysis is that in the recessionary environment following the financial crisis and the on-going European sovereign debt crisis, the carbon price has moved in a very narrow range around €12-15 per metric tonne, without dramatic jumps. Lack of variability in carbon price volatility over this period is likely to be the cause of the high coefficient of determination.

The statistical significance of all the (γ_i +δ) terms motivates a more detailed study of the forecasting power of implied volatility. As a next step, I examine whether implied volatility can be used as a predictor of future volatility over a fixed horizon, independent of the option expiration date, and if so, whether the forecast is efficient and unbiased. The equation $\sigma_{realized,t} = \alpha + \beta\sigma_{implied,t} + \varepsilon_t$ is re-estimated such that $\sigma_{realized,t}$ is the volatility realized over the forecasting horizon = 1 day, 1 week, 1 month, 2 months,…,9 months, respectively. Since the forecasting horizon is shorter than the remaining life of the option, the regression results should be interpreted as indicative of the short-run relationship between implied and realized volatility over different time horizons and the ability of implied volatility to predict changes in the future variance of returns over periods which do not coincide with the life of options. Table 2.5 presents the regression results.

The forecasting accuracy of the ECX implied volatility measure (Panel A) is discussed first. The regression coefficient of implied volatility remains statistically significant under all three alternative measures of realized volatility for all forecasting horizons up to and including 8 months into the future. The significance of implied volatility ($\beta \neq 0$) means that it is informative about ex-post realized volatility and investors are justified to use it as a forecast of volatility over short periods which do not coincide with the remaining life of the option. Numerically, the slope regression coefficients obtained when volatility is measured as squared daily returns are slightly lower than those of the extreme-value estimates. This suggests that implied volatility becomes more important when range-based estimates are used to calculate realized volatility. Under all three alternative definitions of volatility, implied volatility becomes more biased when used as a forecast over longer periods, as evidenced by the steadily declining slope regression coefficients. The Wald test rejects the joint hypothesis that $\alpha=0$ and $\beta=1$ for all three alternative definitions of realized volatility over all forecasting horizons (F-statistics range from 89.26 to 121.92). This confirms that while investors are justified in using implied volatility as a forecast of price variance over short periods in the future, these forecasts are biased.

The results confirm key conclusions from the literature that range-based volatility estimators are better than squared daily returns in capturing the underlying volatility

Table 2.5 Predictive power of implied volatility

This table reports the results of the equation $\boldsymbol{\sigma_{realized,t} = \alpha + \beta\sigma_{implied,t} + \varepsilon_t}$ over multiple forecasting horizons from 1 day up to 9 months. Squared daily returns, Parkinson's and Rogers and Satchell's range-based estimators are used to measure ex-post return variance. The time period is 02/01/2008 – 08/12/2010. Newey-West heteroscedasticity and autocorrelation robust standard errors are employed. P-values of the test β=0 are reported in brackets. Implied volatility ($\boldsymbol{\sigma_{imp}}$) observations are limited to days on which the traded volume of options exceeds zero.

Panel A: Implied volatility is published by the ECX

	Squared Returns RV			**Parkinson RV**			**Rogers and Satchell RV**			
	Intercept	σ_{imp}	Adj. R2	Intercept	σ_{imp}	Adj. R2	Intercept	σ_{imp}	Adj. R2	Obs.
1-day	-13.31	0.92	11.8%	-21.31	1.20	34.2%	-25.20	1.28	36.6%	581
	(0.06)	(0.00)		(0.00)	(0.00)		(0.00)	(0.00)		
1-week	-14.08	1.06	30%	-19.76	1.20	45.9%	-23.09	1.27	48.5%	577
	(0.05)	(0.00)		(0.00)	(0.00)		(0.00)	(0.00)		
1-month	-11.82	1.03	40.2%	-18.38	1.17	52.6%	-21.57	1.23	55.6%	565
	(0.06)	(0.00)		(0.00)	(0.00)		(0.00)	(0.00)		
2-months	-9.29	0.97	40.4%	-16.25	1.12	51.1%	-19.85	1.19	53.9%	548
	(0.09)	(0.00)		(0.00)	(0.00)		(0.00)	(0.00)		
3-months	-5.88	0.90	37.4%	-12.57	1.04	47.2%	-16.13	1.11	49.5%	531
	(0.24)	(0.00)		(0.01)	(0.00)		(0.00)	(0.00)		
4-months	-0.45	0.78	30.5%	-7.56	0.93	40.2%	-11.35	1.00	43%	516
	(0.92)	(0.00)		(0.08)	(0.00)		(0.01)	(0.00)		
5-months	5.66	0.65	22.5%	-1.87	0.81	31.8%	-2.46	0.89	31.1%	495
	(0.20)	(0.00)		(0.66)	(0.00)		(0.58)	(0.00)		
6-months	10.96	0.55	16.3%	3.53	0.70	24.2%	0.38	0.76	26.3%	476
	(0.01)	(0.00)		(0.41)	(0.00)		(0.93)	(0.00)		
7-months	17.65	0.42	10.1%	10.73	0.56	16.4%	8.08	0.61	18.1%	455
	(0.00)	(0.00)		(0.02)	(0.00)		(0.09)	(0.00)		
8-months	25.93	0.26	3.2%	24.14	0.34	4.6%	16.39	0.45	8.2%	435
	(0.00)	(0.04)		(0.00)	(0.02)		(0.02)	(0.00)		
9-months	40.45	-0.01	-0.2%	33.12	0.13	0.4%	31.44	0.16	0.7%	413
	(0.00)	(0.94)		(0.00)	(0.42)		(0.00)	(0.33)		

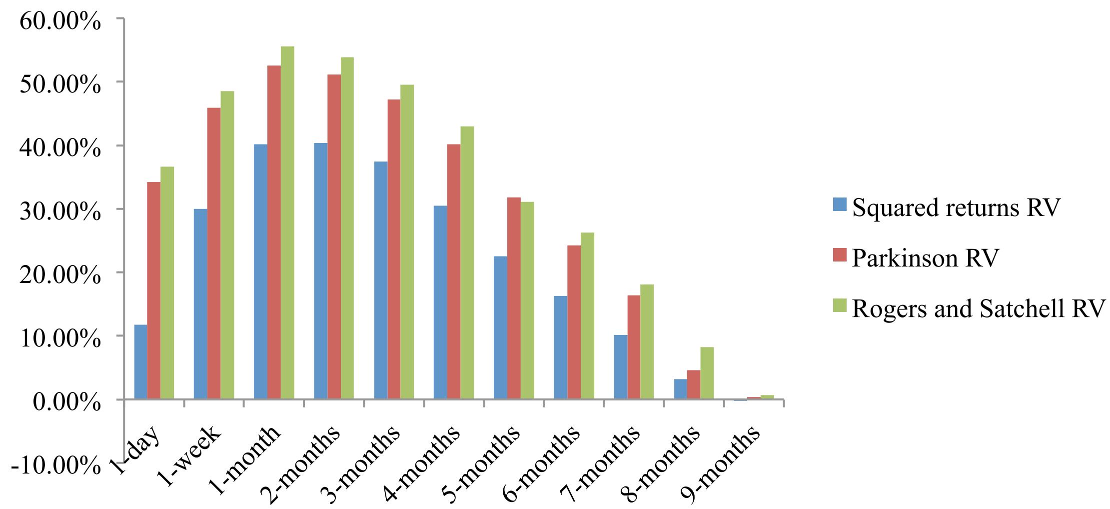
Table 2.5 Predictive power of implied volatility (continued)

Panel B: Implied volatility is derived from the Black (1976) model

	Squared Returns RV			Parkinson RV			Rogers and Satchell RV			
	Intercept	σ_{imp}	Adj. R2	Intercept	σ_{imp}	Adj. R2	Intercept	σ_{imp}	Adj. R2	Obs.
1-day	-13.99	0.96	12.2%	-21.07	1.22	34.4%	-25.06	1.30	37.2%	575
	(0.05)	(0.00)		(0.00)	(0.00)		(0.00)	(0.00)		
1-week	-15.32	1.11	31.1%	-20.26	1.23	46.4%	-23.43	1.30	48.8%	571
	(0.03)	(0.00)		(0.00)	(0.00)		(0.00)	(0.00)		
1-month	-11.84	1.05	39.8%	-18.44	1.20	52.3%	-21.53	1.26	55.2%	559
	(0.07)	(0.00)		(0.00)	(0.00)		(0.00)	(0.00)		
2-months	-7.05	0.94	37.1%	-14.67	1.11	48.5%	-18.48	1.18	51.5%	542
	(0.20)	(0.00)		(0.00)	(0.00)		(0.00)	(0.00)		
3-months	-3.27	0.86	33.6%	-10.52	1.01	44%	-14.15	1.09	46.4%	525
	(0.49)	(0.00)		(0.02)	(0.00)		(0.00)	(0.00)		
4-months	2.15	0.74	26.6%	-5.32	0.90	36.7%	-9.10	0.97	39.5%	510
	(0.62)	(0.00)		(0.20)	(0.00)		(0.03)	(0.00)		
5-months	8.09	0.61	19.3%	0.33	0.78	28.5%	-0.43	0.86	28.2%	490
	(0.06)	(0.00)		(0.94)	(0.00)		(0.92)	(0.00)		
6-months	13.27	0.51	13.5%	5.63	0.67	21.2%	2.49	0.73	23.3%	471
	(0.00)	(0.00)		(0.19)	(0.00)		(0.57)	(0.00)		
7-months	19.44	0.39	8.2%	12.41	0.53	14.2%	9.75	0.59	15.9%	451
	(0.00)	(0.00)		(0.01)	(0.00)		(0.04)	(0.00)		
8-months	28.08	0.22	2.1%	25.89	0.31	3.5%	18.54	0.41	6.5%	429
	(0.00)	(0.10)		(0.00)	(0.04)		(0.01)	(0.00)		
9-months	42.84	-0.06	-0.1%	35.47	0.08	0%	33.76	0.12	0.2	407
	(0.00)	(0.70)		(0.00)	(0.61)		(0.00)	(0.49)		

process (Fleming, 1998; Bakanova, 2010). Panel A of Table 2.5 shows that implied volatility has much more explanatory power (measured by adjusted R-squared) when realized volatility is proxied by either Parkinson's or Rogers and Satchell's extreme-value volatility estimators. Figure 2.1 graphically summarizes the forecasting performance of implied volatility in terms of reported adjusted R-squared values.

Figure 2.1 Improvements in adjusted R-squared over various fixed horizon forecasts with ECX implied volatility as a predictor of realized volatility (RV)



The findings on the forecasting accuracy of Black (1976) implied volatility are reported in Panel B of Table 2.5. The same conclusion holds – implied volatility can be used as a forecast over short periods as well as horizons up to 8 months. The adjusted R-squared reaches its maximum value when Black implied volatility is used as a one-month-ahead forecast. The coefficient of determination for the Black implied volatility regressions is insignificantly lower than that reported for the ECX implied volatility. The maximum adjusted R-squared when using squared returns as a proxy for volatility is 39.8% compared to 40.4% when the ECX-reported volatility is used. For the Parkinson's and Rogers and Satchell's extreme-value volatility measures the coefficients of determination peak at

52.3% and 55.2% respectively (versus 52.6% and 55.6% for the corresponding ECX implied volatility regressions).

In assessing the impact of implied volatility measurement on the relationship between implied and realized volatility, the results do not offer support for the hypothesis that ECX-reported volatility increases the explanatory power of implied volatility since it better captures the market participants' expectations. In order to directly address the issue of which implied volatility specification provides a superior forecast, I employ the J-test for non-nested hypotheses proposed by Davidson and MacKinnon (1981). In a J-test, the two competing model specifications are tested for robustness against each other by including the fitted values of one model in the regression for the other. A model is correctly specified if the added fitted values possess no explanatory power. As a robustness check, I examine the information criteria of the regression estimates and select the model with lower information criteria as a better specification. Table 2.6 presents the results.

The J-test is conducted on significance level of 1%. Since I do not a priori know which model is the "true" model, I conduct two tests for each pair of implied volatilities. Thus, a model that uses, e.g. Black implied volatility will be unambiguously selected over the ECX volatility if and only if the former model is accepted and the latter model is rejected. If both models are either accepted or rejected in this test, the J-test cannot be relied on to select the best model. Out of 36 cases tested in Table 2.6 (three realized volatility specifications for each of the 12 maturities), I can conclude that the J-test clearly supports ECX implied volatility in 6 instances, where the model using Black volatility is rejected and ECX volatility is accepted at the same time. In only 3 of the cases I see such support for the Black volatility. In the remaining 27 cases I am unable to choose between these two

Table 2.6 Comparative performance of ECX-reported volatility and Black implied volatility as a forecast of future variance of returns

This table reports the results of the Davidson and MacKinnon (1981) J-test and the model selection tests based on information criteria. The two competing models considered in the J-test are $\sigma_{realized,t} = \alpha + \beta\sigma_{Black\ implied,t} + \varepsilon_t$ and $\sigma_{realized,t} = \alpha + \beta\sigma_{ECX\ implied,t} + \varepsilon_t$. The period under examination spans from January 2008 until December 2010.

J-test (at 1% significance)		*1-day*	*1-week*	*1-month*	*2-months*	*3-months*	*4-months*	*5-months*	*6-months*	*7-months*	*8-months*	*9-months*	*Until Expiry*
Squared returns	Black IV	Accept	Accept	Accept	Reject	Reject	Reject	Reject	Reject	Reject	Reject	Accept	Reject
	ECX IV	Accept	Accept	Accept	Accept	Reject	Reject	Reject	Reject	Reject	Reject	Accept	Reject
Parkinson	Black IV	Accept	Accept	Accept	Reject	Reject	Reject	Reject	Reject	Reject	Accept	Accept	Reject
	ECX IV	Reject	Reject	Accept	Accept	Accept	Reject	Reject	Reject	Reject	Accept	Accept	Accept
Rogers and Satchell	Black IV	Accept	Accept	Accept	Reject	Reject	Reject	Reject	Reject	Reject	Reject	Accept	Reject
	ECX IV	Accept	Reject	Accept	Accept	Accept	Reject	Reject	Reject	Reject	Accept	Accept	Accept

Information Criteria

All inconclusive

specifications of implied volatility using the J-test. The robustness tests based on the Schwarz and Akaike information criteria corroborate the conclusion that there is no statistically meaningful difference in the performance of ECX and Black volatility as a forecast, as in all 36 cases the comparison is inconclusive. Overall, I do not find evidence to support the hypothesis that the ECX volatility specification provides a better forecast than the Black (1976) estimate. This result implies that market participants' perception of at-the-money implied volatility does not reflect any factors outside the classical pricing models such as the Black model.

2.5.2. Informational efficiency of implied volatility

The results of the test for the informational efficiency of implied volatility against the GARCH-based forecast (Equation 3) are reported in Table 2.7. Panel A presents the results when ECX implied volatility is used and Panel B presents the results when implied volatility is calculated using the Black (1976) model.

To ensure that the OLS analysis does not suffer from multicollinearity, Variance Inflation Factors are estimated. The figures, reported in the column next to adjusted R-squared, are well below 10 which is considered to be the threshold above which multicollinearity is present (Gujarati, 2004). The regression coefficient of implied volatility is statistically significant at the 1% significance level for all three alternative measures across forecasting horizons of up to and including 8 months. Historical volatility is also significant over forecasting horizons up to and including four months and loses its explanatory power for longer-term forecasts. This conclusion is in contrast with Li's (2002) finding that historical-based forecasts outperform implied volatility predictions as the forecasting horizon increases. The difference may be attributable to Li's use of high-frequency data enabling a better modelling of the price volatility dynamics and greater forecasting power than predictions based on daily estimates.

The GARCH forecast coefficient is considerably smaller than the implied volatility coefficient, suggesting that past behaviour is much less important and informative about future volatility. Nevertheless, the statistical significance of historical information-based forecasts found for short-term forecasting horizons implies that using implied volatility as a forecast is inefficient as information contained in recent volatility behaviour is not compounded in the option prices. The results from the efficiency tests against GARCH-based forecasts reported here contrast with the results obtained by Martens and Zein (2004) who find that implied volatility forecasts generally incorporate the GARCH effects. The authors use a non-overlapping methodology and account for the long memory effect in their realized volatility time series, which may account for the difference in the results. Other papers which rely on overlapping sampling methodology, namely Blair et al. (2001) and Neely (2009), generally reach the same conclusions reported in this study.

A direct comparison of the coefficients of determination obtained from these regressions and the rationality regressions in Panel A of Table 2.5 confirms the conclusion that for short forecasting horizons of up to four months ahead implied volatility is indeed an inefficient estimate of future volatility. Adjusted R-squared improves after the addition of historical volatility as an explanatory variable, reflecting the incremental information contained in past futures prices. This result is of importance to all market participants because, as highlighted in Section 2.1, volatility is a critical part of any risk-management process or trading strategy. These conclusions are also confirmed by the results of the regressions estimated using Black volatility as a proxy for the option-implied volatility

(Panel B of Table 2.7).

Similar results, unreported here for the purpose of brevity, are obtained when using historical volatility estimated as the moving average volatility instead of the GARCH model. In this case, historical volatility remains significant for shorter horizons from 1 day to 2 months. This further contributes to the rejection of the information efficiency hypothesis for implied volatility on carbon markets.

One possible explanation for the finding that historical volatility contains information which is not incorporated in implied volatility is that the carbon options market is not yet fully efficient. Due to the relative immaturity of the carbon market, historical price data is only available for a short period, which adds to investors' difficulties in fairly pricing carbon derivatives. Moreover, the presence of regulatory uncertainty and government intervention might act to distort the implied volatility underlying carbon options. If investors continue to fear developments similar to the collapse of the EUA futures price to nearly zero in 2006 when government verified emissions were disclosed, it may be the case that in pricing options they incorporate expectations of high impact, low frequency events that failed to materialise during the sample period (Neely, 2004). This may explain why implied volatility exceeds ex-post realized volatility, regardless of which of the three proxies for volatility is used. As seen in Table 2.1, the average values of realized volatility for all three series are lower than the average values of implied volatility. This leads me to conclude that investors price in possible extreme events in the premium they pay for carbon options.

Table 2.7 Informational efficiency of implied volatility forecasts against GARCH-based forecasts
This table reports the results of Equation 3 in which both implied volatility and GARCH-based forecasts are used as predictors of ex-post realized volatility over multiple forecasting horizons. GARCH parameters for the forecasts during the period 01 – 12/ 2008 were derived from the 2007 log-return series of the underlying ICE ECX EUA futures contracts. GARCH parameters for the forecasts during the period 01-12/2009 were derived from the 2007 and 2008 log-return series of the underlying ICE ECX EUA. Implied volatility observations are limited to days on which the traded volume of options exceeds zero. The period under examination spans from 02/01/2008 until 08/12/2010. Newey-West heteroscedasticity and autocorrelation robust standard errors are employed. The corresponding p-values are reported in parentheses.

Panel A: Implied volatility is published by the ECX

	Squared Returns RV					**Parkinson RV**					**Roger and Satchell RV**					
	Inter-cept	σ_{imp}	GARCH forecast	Adj. R^2	VIFs	Inter-cept	σ_{imp}	GARCH forecast	Adj. R^2	VIFs	Inter-cept	σ_{imp}	GARCH forecast	Adj. R^2	VIFs	Obs.
1-day	-10.46	0.72	0.21	14.9%	1.789	-17.71	0.95	0.26	43%	1.760	-21.55	1.02	0.26	45.1%	1.829	581
	(0.06)	(0.00)	(0.01)			(0.00)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			
1-week	-12.71	0.90	0.18	34%	1.521	-18.20	1.02	0.21	52.2%	2.101	-21.47	1.08	0.21	54.9%	2.226	577
	(0.04)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			
1-month	-13.15	0.92	0.17	43.2%	1.767	-19.84	1.06	0.19	56.3%	2.298	-23.10	1.12	0.20	59.5%	2.477	565
	0.03)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			
2-months	-12.24	0.90	0.16	42.3%	1.740	-19.58	1.05	0.18	53.4%	2.155	-23.44	1.11	0.19	56.4%	2.301	548
	(0.02)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			
3-months	-10.01	0.85	0.17	38.8%	1.641	-17.15	0.99	0.19	48.9%	1.966	-20.97	1.05	0.20	51.3%	2.060	531
	(0.04)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			
4-months	-4.73	0.75	0.15	31.4%	1.463	-12.42	0.89	0.17	41.3%	1.711	-16.37	0.97	0.18	44.1%	1.796	516
	(0.33)	(0.00)	(0.02)			(0.01)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			
5-months	3.42	0.64	0.08	22.6%	1.297	-5.06	0.79	0.11	32.1%	1.478	-3.46	0.88	0.03	30.9%	1.454	495
	(0.51)	(0.00)	(0.33)			(0.29)	(0.00)	(0.14)			(0.51)	(0.00)	(0.69)			
6-months	11.33	0.55	-0.01	16.1%	1.197	2.86	0.70	0.02	24.1%	1.323	-0.25	0.76	0.02	26.2%	1.361	476
	(0.04)	(0.00)	(0.89)			(0.59)	(0.00)	(0.80)			(0.96)	(0.00)	(0.82)			
7-months	19.10	0.43	-0.05	10%	1.116	11.18	0.56	-0.02	16.2%	1.199	8.66	0.62	-0.02	18.3%	1.223	455
	(0.00)	(0.00)	(0.63)			(0.05)	(0.00)	(0.88)			(0.13)	(0.00)	(0.85)			
8-months	28.66	0.28	-0.10	3.2%	1.038	28.37	0.37	-0.16	4.9%	1.057	18.22	0.46	-0.07	8.1%	1.093	435
	(0.00)	(0.03)	(0.39)			(0.00)	(0.01)	(0.23)			(0.01)	(0.00)	(0.57)			
9-months	42.76	0.01	-0.09	-0.2%	1.002	34.68	0.15	-0.06	0.3%	1.008	32.99	0.18	-0.06	0.6%	1.011	413
	(0.00)	(0.94)	(0.46)			(0.00)	(0.39)	(0.62)			(0.00)	(0.31)	(0.64)			

Table 2.7 Informational efficiency of implied volatility forecasts against GARCH-based forecasts (Continued)

Panel B: Implied volatility is calculated by the Black (1976) model

	Squared Returns RV					Parkinson RV					Roger and Satchell RV					
	Inter-cept	σ_{imp}	GARCH forecast	Adj. R^2	VIFs	Inter-cept	σ_{imp}	GARCH forecast	Adj. R^2	VIFs	Inter-cept	σ_{imp}	GARCH forecast	Adj. R^2	VIFs	Obs.
1-day	-11.04	0.75	0.21	15.3%	1.185	-17.30	0.95	0.26	43.4%	1.774	-21.19	1.03	0.27	46.3%	1.868	575
	(0.05)	(0.00)	(0.01)			(0.00)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			
1-week	-13.80	0.94	0.19	35.5%	1.555	-18.58	1.04	0.21	52.9%	2.131	-21.68	1.10	0.22	55.5%	2.255	571
	(0.03)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			
1-month	-13.18	0.94	0.18	43.1%	1.783	-19.90	1.07	0.19	56.2%	2.293	-23.06	1.13	0.20	59.3%	2.467	559
	(0.03)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			
2-months	-10.26	0.86	0.18	39.3%	1.654	-18.20	1.02	0.19	51.1%	2.054	-22.29	1.10	0.21	54.4%	2.200	542
	(0.06)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			
3-months	-7.85	0.80	0.19	35.5%	1.556	-15.53	0.96	0.20	46.1%	1.863	-19.45	1.02	0.21	48.6%	1.952	525
	(0.10)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			
4-months	-2.71	0.70	0.17	27.8%	1.391	-10.74	0.86	0.19	38.1%	1.622	-14.71	0.93	0.20	40.9%	1.699	510
	(0.58)	(0.00)	(0.02)			(0.02)	(0.00)	(0.00)			(0.00)	(0.00)	(0.00)			
5-months	5.35	0.60	0.09	19.4%	1.246	-3.35	0.76	0.12	28.9%	1.413	-1.73	0.85	0.04	28.1%	1.396	490
	(0.30)	(0.00)	(0.28)			(0.49)	(0.00)	(0.12)			(0.75)	(0.00)	(0.63)			
6-months	13.27	0.51	0.00	13.3%	1.158	4.66	0.66	0.03	21.1%	1.273	1.52	0.73	0.03	23.2%	1.307	471
	(0.02)	(0.00)	(1.00)			(0.39)	(0.00)	(0.74)			(0.78)	(0.00)	(0.75)			
7-months	20.55	0.39	-0.04	8.1%	1.093	12.57	0.53	-0.01	14%	1.168	10.03	0.59	-0.01	15.7%	1.191	451
	(0.00)	(0.00)	(0.73)			(0.03)	(0.00)	(0.96)			(0.09)	(0.00)	(0.93)			
8-months	30.33	0.24	-0.08	2%	1.025	29.87	0.34	-0.15	3.8%	1.044	19.87	0.42	-0.05	6.3%	1.073	429
	(0.00)	(0.08)	(0.51)			(0.00)	(0.02)	(0.29)			(0.01)	(0.00)	(0.70)			
9-months	44.69	-0.04	-0.08	-0.2%	1.003	36.56	0.10	-0.05	-0.2%	1.003	34.85	0.13	-0.05	0%	1.005	407
	(0.00)	(0.81)	(0.58)			(0.00)	(0.58)	(0.75)			(0.00)	(0.47)	(0.75)			

2.5.3. DIRECTIONAL ACCURACY OF IMPLIED VOLATILITY FORECASTS

Having established that implied volatility is informative about the future variance of returns, the issue then arises as to whether or not implied volatility actually represents a useful forecast, given its bias in overestimating realized volatility. While research has focused on the ability of implied volatility to predict future volatility, the usefulness of implied volatility forecasts in terms of correct hedging decisions and profitable speculative trades is not generally addressed in the literature on informational efficiency. To an options trader, for example, the direction of changes in volatility is often of greater significance than the actual size of the change. The results of the directional accuracy test are reported in Table 2.8. Again, implied volatility is examined as a forecast multiple steps ahead – ranging from 1 day to 9 months – and realized volatility is measured by the three alternative estimators used in the analysis so far.

The results in Panel A demonstrate that implied volatility has some, although not exceptionally high (rate of correct forecasts is below 60% for all horizons), predictive power for future volatility changes for most forecasting horizons and all volatility measures employed. For all forecasting horizons of one month and above correct forecasts of volatility changes exceed 50% and all are statistically significant, except one-month ahead for the squared returns estimator. The highest percentage of correct predictions is achieved for the longest horizons (8 and 9 months), with the share of accurate predictions reaching 58% for Rogers and Satchell's volatility.

The directional accuracy is also examined for the three individual years of the study (2008, 2009 and 2010) and for the volatility increases and decreases, separately (Panel B of Table

Table 2.8 Directional accuracy of implied volatility as a forecast of ex-post variance of returns

This table reports the results of the directional accuracy tests on implied volatility as a predictor of realized volatility over multiple forecasting horizons. An increase in implied volatility is interpreted as a forecast of increase in ex-post variance of returns, and vice versa. Forecasts are compared to actual changes in the volatility over the following *i* periods where *i*=1 day, 1 week, 1 month… 9 months. Realized volatility (RV) is proxied by three alternative measures – squared daily returns, Parkinson's and Rogers and Satchell's estimators. The percentage of accurate forecasts is individually estimated for correct increases and decreases. The table reports the significance of the accuracy where *, **, and *** imply significance at 1%, 5% and 10% level, respectively.

Panel A: Correct forecasts

		1-day	**1-week**	**1-month**	**2-month**	**3-month**	**4-month**	**5-month**	**6-month**	**7-month**	**8-month**	**9-month**
Total forecasts		580	576	559	537	515	495	475	456	434	412	390
Squared Returns RV	Correct forecasts	284	274	294	298*	289*	274*	263*	253*	240**	236*	216**
		48.97%	47.57%	52.59%	55.49%	56.12%	55.35%	55.37%	55.48%	55.30%	57.28%	55.38%
Parkinson RV	Correct forecasts	273	289	307*	288**	285*	275*	270*	251**	236**	232*	223*
		47.07%	50.17%	54.92	53.63%	55.34%	55.56%	56.84%	55.04%	54.38%	56.31%	57.18%
Rogers and Satchell RV	Correct forecasts	276	295	313*	298*	281**	281*	256**	251**	242*	239*	224*
		47.59%	51.22%	55.99%	55.49%	54.56%	56.77%	53.89%	55.04%	55.76%	58.01%	57.44%

Panel B: Forecasts by year and direction

2008		**1-day**	**1-week**	**1-month**	**2-months**	**3-month**	**4-month**	**5-month**	**6-month**	**7-months**	**8-month**	**9-month**
Squared returns	Actual increases	126	107	116	146	179	198	230	235	226	212	228
	Correct forecasts	54.29%	40%	47.14%	60%**	74.29%*	82.86%*	95.71%*	100%*	94.29%*	88.57%*	97.14%*
	Actual decreases	112	131	122	92	59	40	8	3	12	26	10
	Correct forecasts	48.78%	62.20%**	53.66%	45.12%	30.49%	19.51%	4.88%	2.44%	8.54%	17.07%	6.10%
Parkinson	Actual increases	74	87	87	81	77	77	72	70	70	72	80
	Correct forecasts	47.14%	52.86%	52.86%	58.57%***	74.29%*	87.14%*	100%*	100%*	100.00%*	98.57%*	84.29%*
	Actual decreases	125	129	118	92	60	35	2	0	2	6	42
	Correct forecasts	50%	60.98%**	60.98%**	48.78%	30.49%	19.51%	2.44%	0.00%	0.00%	3.66%	25.61%
Rogers & Satchell	Actual increases	117	113	114	145	172	187	238	237	216	201	197
	Correct forecasts	48.57%	57.14%	47.14%	62.86%**	71.43%*	82.86%*	100%*	100%*	90%*	84.29%*	84.29%*
	Actual decreases	121	125	124	93	66	51	0	1	22	37	41
	Correct forecasts	47.56%	56.10%	58.54%***	54.88%	36.59%	29.27%	0.00%	1.22%	13.41%	23.17%	25.61%

Panel B (Continued)

2009		**1-day**	**1-week**	**1-month**	**2-month**	**3-month**	**4-month**	**5-month**	**6-month**	**7-month**	**8-month**	**9-month**
Squared returns	Actual increases	115	120	87	82	78	50	47	34	34	34	34
	Correct forecasts	48.24%	47.06%	40%	40%	37.65%	23.53%	18.82%	16.47%	16.47%	16.47%	16.47%
	Actual decreases	121	116	149	154	158	186	189	202	202	202	202
	Correct forecasts	50%	46.43%	66.96%*	69.64%*	67.86%*	82.14%*	83.93%*	89.29%*	89.29%*	89.29%*	89.29%*
Parkinson	Actual increases	109	113	88	90	61	43	37	36	35	36	36
	Correct forecasts	37.65%	45.88%	40%	35.29%	23.53%	20%	18.82%	17.65%	16.47%	17.65%	17.65%
	Actual decreases	127	123	148	146	175	193	199	200	201	200	200
	Correct forecasts	45.54%*	51.79%*	66.07%*	60.71%*	73.21%*	85.71%*	88.39%*	88.39%*	88.39%*	88.39%*	88.39%*
Rogers & Satchell	Actual increases	120	110	94	100	81	55	57	39	37	37	37
	Correct forecasts	43.53%	44.71%	45.88%	40%	25.88%	21.18%	21.18%	18.82%	18.82%	18.82%	18.82%
	Actual decreases	116	126	142	136	155	181	179	197	199	199	199
	Correct forecasts	43.75%	54.46%	65.18%*	59.82%**	64.29%*	80.36%*	79.46%*	86.61%*	88.39%*	88.39%*	88.39%*
2010												
Squared Returns	Actual increases	123	110	82	43	30	28	3	0	0	0	0
	Correct forecasts	48.39%	40.66%	35.71%	24%	25.76%	21.82%	2.33%	0.00%	0.00%	0.00%	0.00%
	Actual decreases	116	125	136	153	144	124	127	108	86	64	42
	Correct forecasts	46.38%	48.53%	61.9%*	78.76%*	87%*	83.52%*	97.59%*	100%*	100%*	100%*	100%*
Parkinson	Actual increases	115	113	75	42	26	18	0	0	0	0	0
	Correct forecasts	48.39%	43.96%	33.33%	25.33%	24.24%	10.91%	0.00%	0.00%	0.00%	0.00%	0.00%
	Actual decreases	124	122	143	154	148	134	130	108	86	64	42
	Correct forecasts	51.45%	47.79%	66.67%*	79.65%*	90%*	86.81%*	100%*	100%*	100%*	100%*	100%*
Rogers & Satchell	Actual increases	120	113	83	45	21	2	15	0	0	0	0
	Correct forecasts	51.61%	46.15%	42.86%	26.67%	21.21%	1.82%	11.63%	0.00%	0.00%	0.00%	0.00%
	Actual decreases	119	122	135	151	153	150	115	108	86	64	42
	Correct forecasts	50%	50%	66.67%*	77.88%*	93%*	98.9%*	89.16%*	100%*	100%*	100%*	100%*

2.8). Overall, a trend of increasing volatility is reported over 2008, and over this year implied volatility is found to be more directionally accurate in predicting volatility increases than decreases. In fact, 100% accuracy is reported for predictions of ex-post volatility increases over several of the forecasting horizons across all three volatility measures used. Unlike 2008, both 2009 and 2010 were marked by a long-term trend of decreasing volatility. This steady decline in price volatility may be interpreted as a sign that the carbon market is becoming increasingly mature and less uncertain. In particular, during 2009 and 2010 the European Commission confirmed details about the continuation of the EU ETS after 2012 and the emission caps for the third trading period. Alternatively, the decreasing volatility may be a consequence of the recessionary environment in Europe over the period. Declining industrial production reduced demand for emission allowances and pushed carbon prices down. For these two years, implied volatility was directionally more accurate in forecasting future volatility decreases rather than increases.

Thus, the sample has included periods of both volatility increase and decline, and over the whole period, I find that implied volatility has a statistically significant power to predict future volatility changes, especially for longer horizons.

2.6. Conclusions

This chapter investigates the forecasting accuracy of implied volatility in the rapidly developing carbon options market. The findings suggest that the implied volatility of carbon options is highly informative about the future volatility up to a year ahead. Implied volatility, obtained from direct surveys of ECX market participants, and Black implied volatility perform equally well as a forecast of future variance. The results do not support the hypotheses of unbiasedness or efficiency. On the contrary, I find that historical volatility contains incremental information which is not contained in the implied volatility estimate, especially when forecasting volatility over shorter periods of time. This would imply that speculative opportunities for arbitrageurs exist in the carbon market and profits could be made by trading on a combination of historical price data and option implied volatility. The results also suggest that implied volatility is directionally accurate in predicting future volatility changes. This chapter has focused on short-term point forecasts, which are likely to be of particular importance to carbon traders and regulated emitters.

The assessment of the impact of different measures of realized volatility on the relationship between implied and realized volatility confirms the view that range-based estimators increase the explanatory power of implied volatility since they better capture the underlying volatility dynamics. Rogers and Satchell’s estimator performs slightly better than Parkinson’s estimator due to the fact that it allows for jumps in the opening price of the carbon futures.

In interpreting the results of the study, some caveats are necessary. First, despite the rapid growth of the carbon options market, its liquidity and size remain much smaller than other financial or commodity markets. The data set also coincides with the recent financial crisis. Lower levels of industrial production have reduced the demand for emission allowances and the restricted credit environment has led firms to monetize allowances to raise funds (World Bank, 2010). Much of the recent trading activity can therefore be attributed to short-term, time-specific circumstances, which may not reflect the longer term market fundamentals. Availability of longer data series in the future will allow an assessment of the impact of the global financial crisis on the results presented in this chapter.

CHAPTER 3 INFORMATIONAL EFFICIENCY IN THE CONTEXT OF A CHANGING INSTITUTIONAL FRAMEWORK

3.1. INTRODUCTION

On March 11th, 2011 a devastating earthquake caused a radiation leak at the Japanese nuclear plant Fukushima. In response to the nuclear reactor crisis in Japan, industrialized European nations immediately questioned the nuclear future of their economies. The German Chancellor Angela Merkel was the first political leader to commit to the suspension of multiple nuclear reactors in the country. Her announcement caused an instantaneous jump in carbon prices[6]. Speculation over the increased demand for coal in the face of future reductions in nuclear energy output gave rise to a significant increase in the price of carbon allowances. Such evidence from the market seems to suggest that market participants are able to accurately price in new information. The aim of this chapter is to empirically investigate if, and to what extent, the carbon market is efficient. An event study methodology is employed to examine if new information reaching the market affects the expected price of carbon futures contracts, thereby causing abnormally positive or negative returns.

Examining the issue of informational efficiency is particularly important for the European Union Emissions Trading Scheme as this fairly new market is undergoing constant structural and institutional changes. These changes are driven by the continuous learning process of policy makers and their attempts to improve the existing structures,

[6] http://www.businessgreen.com/bg/news/2033960/carbon-price-spikes-japan-nuclear-crisis

administrative processes and regulation of the market (Koop and Tole, 2011). Some of the major transformations in the organizational set-up of the market have been the move away from individual National Allocation Plans (NAPs) to a centralized EU-wide emissions cap, and the implementation of the Linking Directive which connects the EU ETS with Kyoto projects. The ability of market participants to accurately form expectations about the future price dynamics in such a continuously evolving institutional framework is crucial for the effective functioning of the carbon market.

The efficiency of the carbon market has already been investigated in several academic papers but the results are far from unanimous. Miclaus et al. (2008) examine whether carbon market participants incorporate new information about announcements related to Phase I and II National Allocation Plans and about releases of verified emissions data during the first three years of the scheme. No evidence of cumulative abnormal returns is found, leading the authors to conclude that market participants accordingly account for new information and accurately forecast future price movements as a consequence of these announcements. Examining the same set of announcements as Miclaus et al. (2008) but using a different carbon return-generating model, Mansanet-Bataller and Pardo (2009) document statistically significant market reactions before and after the events. Such findings are inconsistent with the weak-form market efficiency hypothesis.

Chevallier et al. (2009a) demonstrate that information disclosure by the European Commission (EC) has a considerable impact on carbon price formation. They examine the public release of verified emissions data for 2006 and document a reduction in the volatility of carbon prices after the event as misleading information and uncertainty are removed from the market. Employing high-frequency data, Rotfuβ et al. (2009) construct a model of expectation formation whereby market participants forecast the decision of the European Commission on the proposed Phase II National Allocation Plans. The authors find that new information is accurately incorporated in carbon prices but with a considerable delay, implying that the market is not fully informationally efficient yet. In a recent work, Lepone et al. (2011) highlight a high level of informational asymmetry and data leakage observed in the carbon market. They too, find no support for the weak-form efficiency hypothesis and report cumulative abnormal returns associated with these types of institutional announcements.

This chapter contributes to the existing literature on the informational efficiency of the carbon market in several ways. First, it is the first comprehensive work to include announcements related to Phase I, II and III of the EU ETS and their impact on the prices of near maturity and near phase futures contracts across all three trading periods. Second, a considerable improvement over the existing literature is the addition of new informative events for analysis. Prior research has focused on a limited set of supply-related announcements which cover news about the individual National Allocation Plans and the annual releases of verified emissions data. In addition to these, this chapter includes demand-side announcements related to the scope of the scheme, the linkage with tradable Kyoto offsets, the eligibility of alternative carbon certificates for ETS compliance, and the United Nations' Conference of Parties. Third, I examine the impact of macroeconomic conditions on the market responsiveness to these announcements. Lastly, while most studies so far have examined the impact of events on the variance of carbon returns, I examine option-implied volatility changes around multiple event days too.

An event study based on regression analysis is performed where carbon returns are modelled as a function of: 1) event dummies only, and 2) energy variables, the stock market and extreme weather in addition to the event dummies. With both specifications, significant price reactions are detected following announcements about the different aspects of the EU ETS institutional and organizational construct. Releases of verified emissions data are shown to have the strongest price impact. For the majority of the analysed events, the direction of the market response on the event day is as expected. Although price changes accurately reflect new information, market participants do not seem to be able to evaluate its implications for carbon prices across the different trading periods of the scheme. Therefore, I infer that the market is not fully informationally efficient yet. Evidence is found that the EU ETS has become less responsive to institutional disclosure following the start of the financial crisis. I confirm findings in prior literature that the variance of carbon returns remains unaffected by these announcements. At the same time, I document statistically significant changes in option implied volatility around scheduled events like the release of verified emissions data and the United Nations' Conference of the Parties.

Section 3.2.1 presents the institutional framework and administrative structure of the EU ETS, followed by a brief overview of the relevant research on the topic of carbon market efficiency in Section 3.2.2. Hypotheses are formulated in Section 3.3, the methodology and data are presented in Sections 3.4 and 3.5, respectively. These are followed by empirical results and conclusions.

3.2. Literature review

3.2.1. Institutional framework of the EU ETS

The EU ETS was designed to have separate trading periods. Phase I (2005-2007) was a trial period with the objective of kick-starting the market and setting up its institutions. Phase II (2008-2012) coincides with the Kyoto Protocol commitment period and requires EU member states to achieve an 8% emission reduction below their 1990 level. The European Commission has already guaranteed the continuation of the scheme until 2020 at least, although the Kyoto Protocol expires at the end of 2012.

3.2.1.1. The National Allocation Plan (NAP)

The National Allocation Plans of individual member states outline the overall amount of European Union Allowances (EUAs) available to covered companies during the first and second phase of the scheme. As briefly mentioned in Section 1.1 of the thesis, it is the responsibility of national governments to decide on the total emissions caps. Having a NAP approved is a multi-stage process. First, a draft plan needs to be published for public consultation before it is formally submitted to the EC. After the EC receives the draft plan, it has three months to assess it and announce a decision on whether to accept or reject it. If a NAP is rejected, revisions are carried out until a final version is finally approved. Only then, can governments allocate EUAs across covered installations. Due to the complex nature of the process surrounding the formulation and acceptance of individual NAPs, there are very frequent unscheduled announcements by both the EC and the individual governments (Mansanet-Bataller and Pardo, 2009; Lepone et al., 2011).

Different NAPs were in force during the two separate trading periods to date of the ETS. From 2005 to 2007 all EUAs were given away for free to covered entities even though member states were allowed to auction up to 5% of their allowances (Veith et al., 2009). As noted by Fankhauser (2011), the 2 billion carbon allowances which were given away constituted "a €30 billion transfer to Europe's most carbon-intensive firms". A maximum of 10% of the total EUAs is allowed to be auctioned during Phase II. Following severe criticism over the way in which allowances were distributed during the first two trading periods, the EC is replacing the 30 separate NAPs with a single EU-wide emissions cap in Phase III. The targeted emission reduction during the third trading period is 30% of the 1990 benchmark levels and starting in 2013, the majority of EUAs are intended to be auctioned[7].

3.2.1.2. Verification

Every year by the end of March regulated installations are required to submit to the EC an independently verified report of the amount of carbon emissions for the previous calendar year. Firms must then surrender an equivalent number of carbon allowances to match their actual emissions by the end of April. Failure to do so results in a monetary penalty (€40 per tonne of carbon during Phase I and €100 during Phase II) and the entity remains liable to cover the shortfall in the next year. Inter-temporal borrowing and banking of EUAs during a trading period is allowed so that a company which has emitted more than its cap can borrow allowances from the next year's allocation. Banking between Phase I and II was not

[7] European Commission, <http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/08/35>

allowed but the restriction was lifted between Phase II and III. The EC publicly discloses the verified emissions data in April/May each year.

3.2.1.3. The Linking Directive

In November 2004, the EU adopted the Linking Directive (EU Directive 2004/101/EC) which recognizes Clean Development Mechanism (CDM) and Joint Implementation (JI) carbon offsets for ETS compliance purposes. Certified Emission Reductions (CERs) are carbon offsets created under the CDM and Emission Reduction Units (ERUs)[8] - those created under the JI mechanism. Under the CDM, reductions of carbon in non-Annex B Kyoto countries (developing countries with no legally binding emissions reduction targets) can be rewarded with CERs. Annex B countries (industrialized countries with legally binding emissions reduction targets) can purchase these project-based offsets and use them towards their own carbon reduction targets. Member States have freedom to decide on the exact amount of offsets which covered facilities can use in lieu of EUAs. For example, Slovakia has completely forbidden the use of CERs and ERUs for ETS compliance in Phase II; the United Kingdom, Germany and Italy limited the use of offsets to 10% of overall allocations, while Poland and Spain decided on 25% (Convery and Redmond, 2007). The treatment of CDM/JI carbon offsets for the third trading period of the EU ETS is still very uncertain.

Due to the restrictions on the amount of offsets which can be used for compliance purposes, EUAs and CERs are not fully fungible although they both represent the right to

[8] ERUs have not been particularly popular compliance alternatives for covered entities - they represented a mere 0.01% of the total surrendered allowances at the 2008 annual compliance event (Trotignon and Leguet in Mansanet-Bataller et al., 2010). Trading in ERUs attracted investor attention only in late 2010 (Koop and Tole, 2011). Thus, ERUs are ignored from the analysis and the study is limited to announcements about the ability of covered entities to use CERs for compliance purposes.

emit a tonne of carbon dioxide in the atmosphere (Mansanet – Bataller et al., 2010). Their prices are, however, tightly linked due to the active participation of covered entities in the CDM market (Fankhauser, 2011). What is more, CERs are becoming an increasingly important price driver for the European carbon market (Koop and Tole, 2011). Using project-based offsets became a viable option for mandated facilities only after 2008, when the Kyoto Protocol's International Transaction Log (ITL) was linked to the Community Independent Transaction Log (CITL) of the EU ETS and offsets could be electronically transferred thereafter. Therefore, during Phase II of the scheme EUA prices no longer reflect European supply and demand considerations only. From 2008 onwards, the carbon price captures the EU ETS market as well as the international CER market (Mansanet – Bataller et al., 2010; Koop and Tole, 2011). The availability of CERs, quoted at a discount to EUAs, has put a downward pressure on the price of EUAs (Convery and Redmond, 2007).

3.2.2. Previous studies on the efficiency of the EU ETS

3.2.2.1. The impact of NAP announcements on carbon returns

Several event studies have examined market responses following announcements made by the EC and national governments with regards to the National Allocation Plans. For example, Miclaus et al. (2008) investigate whether the December 2007 carbon futures price reflects new information about Phase I and II NAPs. Their study covers 42 NAP announcements over the period 22/04/2005 – 17/12/2007. Carbon returns are modelled according to an autoregressive GARCH process which is continuously recalibrated starting from 100 days before the beginning of the event window. The calibration window moves one day forward for each announcement, providing a one-day ahead forecast of futures returns. Abnormal returns are estimated against the AR-GARCH forecast over an event window of 21 days: 10 days before and 10 days after the event day.

Miclaus et al. (2008) find significant abnormal returns associated with only few of the announcements on the event day and no statistically significant cumulative abnormal returns. A possible explanation for the documented lack of significant market response is that the methodology chosen to forecast normal returns might introduce a bias. Since announcements in the carbon market occur with a high frequency and any two events take place within less than 100 days of each other, the calibration window of 100 days before the event window includes abnormal returns from any announcements that have taken place during that calibration period. A biased forecast of normal returns will lead to wrong estimates of abnormal returns and might cause the researchers to commit a Type II error by concluding that certain events did not bring about excess returns when, in fact, they did.

In a later study, Rotfuβ et al. (2009) focus only on the impact of NAP announcements by the EC and demonstrate that Phase II carbon futures prices are sensitive to apporvals of National Allocation Plans. Over the period 29/11/2006 – 26/10/2007 the authors identify 27 plan acceptances, corresponding to 14 events dates[9]. Anticipated Phase II emissions caps are assumed to be proportional to the Phase I allowances granted to the respective country. The difference between EC-approved allocations and anticipated allocations is defined as news to the market. The amount of unanticipated allocations is used as an exogenous variable and regressed against carbon returns in order to identify excess returns around NAP acceptances. Returns are calculated around ten-minute intervals. Positive

[9] Announcements about the allocation plans of several member states are often released on the same day.

excess returns following unanticipated decreases in the proposed NAPs and negative excess returns following unexpected over-allocations of EUAs are reported. New information is incorporated in prices with a lag of up to 6 hours, leading the authors to conclude that the market is not yet fully efficient.

Similar to Miclaus et al. (2008), Mansanet-Bataller and Pardo (2009) study the impact of Phase I and II NAP announcements on the nearest-to-expiry Phase I carbon futures prices. The 70 announcements identified over the period 25/10/2004 – 18/05/2007 are shown to have a significant impact on carbon returns. For the period 25/10/2004 – 30/11/2005, the European Carbon Index[10] is used to proxy futures prices. For the remainder of the sample period, the authors employ the nearest-to-expiry futures contract quoted on the European Climate Exchange. Two event study methodologies are adopted – a regression analysis and a constant mean return model. In the regression framework, carbon returns are modelled as a function of coal, gas and oil returns. Event days are included as dummy variables. The second methodology – the constant mean return model - is adapted to take into account the high frequency of unscheduled information releases. A trimmed mean return model is estimated, whereby 10% of the highest and 10% of the lowest returns during the estimation period are removed. Estimation periods of 10, 20 and 30 days before the event window are used.

Notifications of Additional Information and Approvals of Phase I NAPs are found to be associated with statistically significant positive abnormal returns. Announcements related to Phase II NAPs are shown to have a significant and negative impact on Phase I futures. Upon closer inspection of the event days the authors use, I identify several inconsistencies

[10] The European Carbon Index is an index of over-the-counter forward carbon price calculated by the European Energy Exchange.

and event misclassifications. Mansanet – Bataller and Pardo wrongly classify certain events (for example, UK Phase I NAP was actually rejected on the 22 Feb 2006, while the authors identify it as an acceptance). Also, they treat the rejection of a NAP as a Notification of Additional Information to the EC (as in the case of the UK NAP I rejection of April 12th, 2005). Such misclassification could arguably yield misleading results.

Lepone et al. (2011), replicating the methodology of Mansanet-Bataller and Pardo (2009), examine the effect of Phase II NAP announcements on the prices of nearest-to-expiry as well as December 2008 EUA futures contracts over a more recent time period. Their study improves on earlier works by employing releases of information in the media (e.g. the Point Carbon news database) prior to official EC announcements. Over 170 NAP II announcements are documented during the period 01/02/2006 – 31/12/2008. Lepone et al. (2011) report contradictory results for the same events when the two different event study methodologies are employed. Using ordinary least squares (OLS) analysis, significant negative abnormal returns are found for the nearest-to-expiry futures contracts around notifications of additional NAP II information, conditional approvals, amendment approvals and verification releases. With the truncated mean return model the authors obtain a significant positive excess return surrounding the days of the initial plan notifications only and significant negative excess returns surrounding all remaining NAP events. The authors create very narrow categories for NAP announcements which leads to few event days per category. This fine classification raises issues about the reliability of the t-statistics and the significance of the associated abnormal returns.

3.2.2.2. The impact of verification events on carbon returns

Prior studies have highlighted the importance of annual verification events in addition to NAP announcements. For example, Chevallier et al. (2009a) document a shift in the risk attitudes of carbon market participants following the public release of verified emissions for 2006. The authors also document an implied volatility smile skewed to the right before the release of verified data which is consistent with an expectation of a carbon price decline. After the event, however, the smile is skewed to the left. The verification event revealed that the EU was net long in 2006, which would explain the expected decrease in the price before the event. Absolute risk aversion is extrapolated from the risk-neutral distribution of option prices and the historic distribution of ECX futures returns. The risk-neutral probability distribution is derived from the Black-Scholes (1976) implied volatility of carbon options via a non-parametric kernel regression, while the historical distribution is approximated by the historical return distribution of the December 2008 and 2009 futures prices using a semi-parametric asymmetric GARCH model. The sample covers the period from 1 October 2006 up until 23 November 2007. The strong impact of the verification events on the carbon price dynamics is corroborated in Miclaus et al.(2008), Mansanet – Bataller and Pardo (2009) and Lepone et al. (2011), all of whom report statistically significant abnormal returns associated with these events.

3.2.2.3. The impact of NAP announcements and verification events on the volatility of carbon prices

With regards to the impact of institutional announcements on the volatility of carbon prices, the findings are mixed. Chevallier et al. (2009a) find evidence that verification events impact investors' beliefs by removing misleading information and uncertainty from the market. The authors demonstrate that both the volatility of futures contracts and the option implied volatility substantially decline after the 2006 compliance event. Mansanet-Bataller and Pardo (2009) and Lepone et al. (2011) evaluate the impact of announcements on the volatility of carbon returns with sign and Brown-Forsythe (1974) tests. No significant change in the variance of carbon returns is found following NAP announcements and verification events. The lack of change in volatility coupled with significant abnormal returns on days prior to the official releases of data is interpreted as information leakage in the market. I question this explanation because information leakage would increase volatility significantly prior to the actual event as investors act on the news.

Table 3.1 summarizes the previous studies on the carbon market's informational efficiency. In brief, the results are far from conclusive. Miclaus et al. (2008) find only limited evidence that NAP announcements affect the carbon price dynamics while Rotfuβ et al. (2009), Mansanet-Bataller and Pardo (2009) and Lepone et al. (2011) report the opposite. This leads the former to argue that the market is weakly efficient while the latter maintain the contrary. Mansanet-Bataller and Pardo (2009) and Lepone et al. (2011) report that institutional announcements have no impact on the variance of futures returns while Chevallier et al. (2009a) document a reduction in volatility after the 2006 annual disclosure of verified emissions data. All that the authors unanimously agree on is the importance of verification events for the carbon price formation. The observed differences in results across studies may be partially due to differences in the employed methodologies. The authors differ in their definition of a newsworthy announcement, the time period under examination, the classification of events, and the carbon return-generating model. Further research in the area is certainly needed to reconcile the reported contradictory findings.

Table 3.1 Overview of past event studies on the EU ETS institutional disclosures and their impact on carbon prices

Authors	Type of events	Dataset	Number of events	Methodology	Results
Miclaus et al. (2008)	Phase I and II NAPs and Phase I VERs on Phase I (2007) futures	22/04/2005 – 17/12/2007	42 NAPs 3 VERs	AR-GARCH model	No statistically significant cumulative abnormal returns following NAP and verification events
Rotfuβ et al. (2009)	(conditional) approvals of Phase II NAPs from the first time on 2008 EUA futures	29/11/2006 – 26/10/2007	27 NAPs	Model of expectations which uses OLS regression	Positive (negative) abnormal returns following EC under- (over) allocations of NAPs with a lag of 6 hours
Mansanet - Bataller & Pardo (2009)	Phase I and II NAPs and Phase I VERs on Phase I OTC forwards	25/10/2004 – 18/05/2007	72 NAPs & 3 VERs (all) 37 NAPs & 2 VERs (no events 3 days before) 21 NAPs & 1 VER (no events 3 days before and after)	OLS regression with dummies Truncated Constant Mean Return model	1) NAP I and II announcements have had a significant impact on Phase I futures 2) Verification events have led to abnormal returns 3) No change in volatility following the events
Lepone et al. (2011)	Phase II NAPs & Phase I VERs on nearest-to-maturity EUA futures and Phase II futures (December 2008 expiry)	01/02/ 2006 – 31/12/ 2008	124 NAPs & 11 VERs (all) 39 NAPs & 4 VERs (no events 3 days before) 15 NAPs & 2 VERs (no events 3 days before and after)	OLS regression with dummies Truncated Constant Mean Return model	1) NAP II events lead to abnormal returns in Phase II futures and have no impact on Phase I futures 2) No change in volatility following the NAP and verification events

3.2.2.4. A gap in the literature

A shortcoming of the existing literature is the limited scope of the analysed announcements. Only events related to National Allocation Plans and releases of verified emissions data have been examined to date. Both of these event categories refer to the supply side of the carbon market – NAPs set the supply constraints and at the annual compliance events remaining supply in the market is revealed as the amount of verified emissions data is made public. Despite their seeming importance for carbon price development, no announcements related to the demand for carbon certificates has been analysed in the framework of an event study assessing the carbon market efficiency so far. There is also a gap with regard to the impact of announcements about the post-2012 supply of carbon certificates on Phase III futures. Some authors have focused on announcements strictly related to Phase I of the ETS (Chevallier et al., 2009a) while others examine announcements strictly related to Phase II (Rotfuβ, 2009; Lepone et al., 2011). Mansanet-Bataller and Pardo (2009) and Miclaus et al. (2008) offer a more comprehensive analysis by focusing on Phase I and II NAP announcements. No published study has featured the impact of Phase III announcements on Phase III futures contracts. The updated dataset used in this chapter allows me to assess the impact of the financial crisis on the sensitivity of such announcements, an issue which has not been examined earlier either.

3.3. Hypotheses development

This section presents the categories of announcements used in the analysis and the testable hypotheses. Events which affect both the demand for and supply of carbon allowances are examined. The set of supply-related announcements discussed in prior literature is expanded by including news about the centralized post-2012 emissions cap and the new allowance allocation rules. One point worth mentioning is that the publication of installation-level NAPs is not included in the analysis and the focus is only on the overall emissions caps of individual member states. The rationale is that once a country's overall emission reduction target is set, allowance allocation across covered installations within the country has a much smaller, if any, impact on the carbon price. It is the EU-wide cap that determines the scarcity of carbon permits. The analysed demand-side events include announcements about the expansion of the ETS, the CITL-ITL linkage, the acceptability of CERs in lieu of EUAs for compliance, the United Nations' Conference of the Parties and unilateral commitments by the UK and Germany. A detailed list of all categories and the number of announcements which have been identified within each category can be found in Table 3.2. Figure 3.1 graphically presents the variety of announcements examined. These broadly encompass the following:

- Phase I NAP announcements (including Notifications of additional information to submitted NAPs and EC decision on the NAPs). Announcements regarding the first trading period are included in the analysis as Phase I was launched before all the allocation plans were approved. The Greek plan, for instance, was accepted by the EC 6 months after the official launch of the ETS, in June of 2005.
- Phase II NAP announcements (including Information releases about Phase II NAPs before their formal submission to the EC – government publications outlining proposed allocation plans, disclosure of plans for public discussion before formal submission to the EC, NAP information leaked by EC or government representatives in industry newswires like Point Carbon; Initial notifications of plans to the EC whereby member states officially

submit their proposal to the EC; notifications of revision to the proposed plans; EC decisions)

- Phase III announcements (including formal and informal proposals for reduction targets and changes in auctioning rules from 2013 onwards).

- Verification events (releases of data for actual and verified emissions during the years from 2005 through to 2010)

- Other non-NAP related news (including announcements about the scope of the ETS, the availability of CERs for compliance purposes, CITL-ITL linkage). These are all demand-side announcements.

Announcements related to the scope of the EU ETS are classified in a separate group. Within the group, I examine the impact of increasing the scheme's scope in terms of country coverage and sectoral coverage. The second trading period of the programme has already seen the addition of three new countries - Norway, Lichtenstein and Iceland. Croatia has been contemplating emissions trading as well. Sectoral coverage will increase after the inclusion of the aviation industry, petrochemicals, ammonia and aluminium in 2013. The inclusion of the shipping, transportation and IT industries has been proposed, with no success as yet. The expanding scope of the EU ETS suggests that more market players will become involved in the market, boosting traded volumes and improving market liquidity.

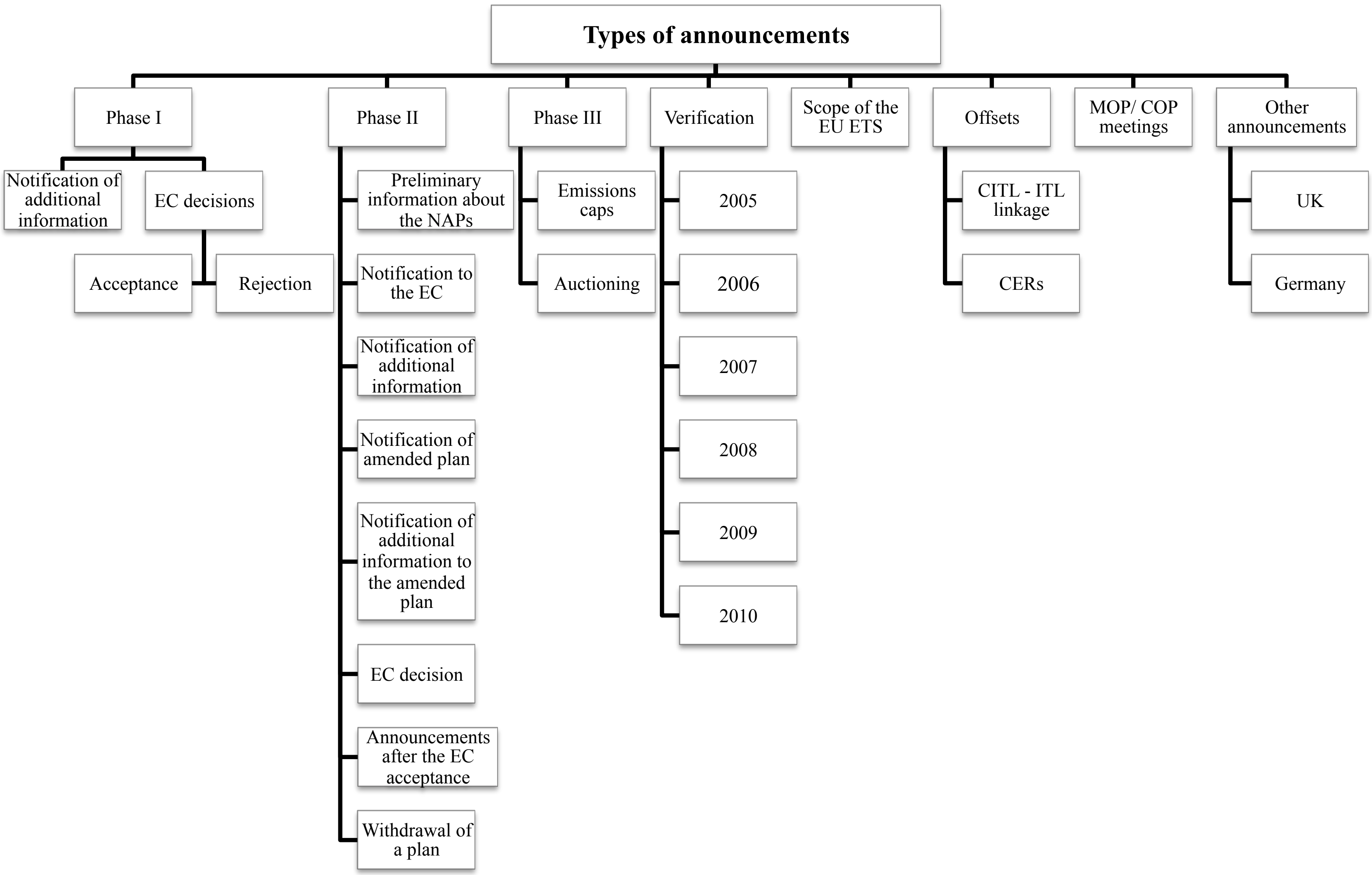
The important role which the Linking Directive has played for the European carbon market was explained in detail in Section 3.2.1.3. The growing use of CERs directly influences demand for EUAs as these project-based carbon offsets can be used as EUA substitutes for compliance purposes. Therefore, uncertainty about the availability of CERs induces instability in the price of EUAs. I examine announcements related to the ability of covered entities to use CERs for compliance purposes and the limits on the acceptability of certain types of CDM projects. For the purposes of the analysis, I identify two types of news within the "Kyoto Offsets" category: CITL-ITL linkage announcements and news about the availability of CERs for EU ETS compliance as I expect different reactions to the two types of announcements.

Announcements made by Germany and the United Kingdom about their targeted emissions reductions are included in a separate category. These two countries are the largest emitters of carbon under the EU ETS. During the pilot phase of the scheme 1,800 German installations received over 1.4 out of the total 6.4 billion metric tonnes of EUAs allocated across Europe. The UK came second, with a total of 1,000 installations which received slightly over 0.7 billion EUAs[11]. The assumption is that carbon developments in the UK and Germany, which represent a substantial share of total carbon allowances, might have a significant impact on the carbon price dynamics. The sample includes announcements about emissions reduction objectives, new national carbon legislation, and choices made when transposing the EU Linking Directive into national law.

The annual meetings of the United Nation's Conference of the Parties (COP) make up the last category of analysed events. COP is the governing body of the United Nations Framework Convention on Climate Change (UNFCCC) and acts as its ultimate decision-making authority. After Russia ratified the Kyoto Protocol in 2005, the COP meetings coincide with the Meetings of Parties (MOP). These events indirectly affect demand for EUAs by deciding on the fate of the Kyoto Protocol and the project-based carbon offsets

[11] European Commission, Emissions Trading Scheme Registries. Available online at: http://ec.europa.eu/clima/policies/ets/index_en.htm

Figure 3.1 Types of announcements



Source: Author

Table 3.2 Types of announcements

This table lists all event categories and the number of events in each category. Column two reports the total number of identified events. Column three reports only the number of events with no same-day announcements, and column four – the number of events with no confounding influences on the previous or following day.

Types of announcements	Total	No same-day events	No events on days +1 or -1
NAP I: Notification of additional information	12	6	2
NAP I: Notification of amendments	1	0	0
NAP I: Acceptance by the EC	5	2	1
NAP I: Rejection by the EC	3	1	1
NAP II: Leaked information before formal submission to the EC	44	28	10
NAP II: Notification of the plan to the EC	27	16	4
NAP II: Notification of additional information	43	35	4
NAP II: Notification of amended plan	16	8	2
NAP II: Notification of additional information to amended plan	20	16	2
NAP II: Acceptance by the EC*	27	13	7
NAP II: Rejection by the EC	12	1	0
NAP II: Withdrawal of a plan	2	1	0
NAP II: Announcements after an official EC decision	8	6	3
Phase III: Emissions caps	15	13	7
Phase III: Auctioning rules	12	11	6
Scope of the EU ETS	32	29	17
CITL – ITL linkage	2	2	2
CERs	8	7	5
Other announcements: UK	8	7	5
Other announcements: Germany	2	2	1
COP/MOP meetings	6	6	4
Verification 2005	6	1	1
Verification 2006	1	0	0
Verification 2007	1	1	1
Verification 2008	4	4	1
Verification 2009	1	1	1
Verification 2010	1	0	0
Total	283	217	87

*In the category "Acceptance", I make no separation between conditional acceptances, acceptances of revised plans and acceptances from the first time

**All OLS regressions results using the events from the third column are presented in Appendix 3B

***All results presented in the main body of text use the events from the last column created under its flexibility mechanisms. For instance, the dialogue about a post-2012 international agreement began at COP 11/MOP 1 in Montreal, Canada. The meeting was a hallmark for the development of emissions trading since until then the continuation of the Kyoto Protocol after 2012 was uncertain and this impeded the trading of CERs. Identifying an exact event day for the annual COP meetings is very arbitrary as they last from 10 days up to two weeks. Due to the sheer length of the meetings, unofficial information about their outcomes might be released to the market as the meetings progress. As history has shown, however, participants at the meetings tend to reach an agreement at the last minute under the pressure of public scrutiny[12]. That is why the last day of the meetings is identified as the event day. I examine announcements related to the outcomes of the COP/MOP annual meetings over the period April 2005 – June 2011, for a total of 5 meetings.

H_1: Announcements which suggest increases (decreases) in the supply of EUAs in the system are expected to result in a negative (positive) price reaction. Similarly, announcements which suggest increases (decreases) in the demand for EUAs are expected to result in a positive (negative) price reaction.

A priori, I anticipate that certain categories of announcements will be associated with positive event returns. These include notifications of amended allocation plans by national governments, plan rejections by the EC and announcements about the availability of CERs for compliance. Plans are rejected when the EC deems the

[12] Just a few examples to illustrate: " in Montreal, where it refused until the last minute to allow even an informal dialogue on post-2012 action" : http://www.c2es.org/docUploads/Pew%20Center_COP%2013%20Summary.pdf
"a last-minute gathering of 25 countries forged the text of the Copenhagen Accord" : http://www.stanford.edu/group/ipsblog/cgi-bin/wordpress/2011/04/looking-to-durban-lessons-from-copenhagen-and-cancun/

emission reduction targets proposed by Member States as insufficiently strict. An amended plan is then presented by the national government. Therefore, both of these announcement categories imply further reductions in the emission targets for EU Member States. The CER-related announcements examined in this chapter refer to the process of banning the use of certain gases for generating carbon offsets. This implies a lesser supply of CERs reaching the EU ETS market and hence higher EUA prices.

Notifications of additional information to original or amended plans may not necessarily lead to a significant price reaction as these additions could be elaborations of proposed plans rather than revisions of the targeted emission reductions. NAP acceptances are not expected to have a significant impact on carbon prices either as all the information about the emissions caps contained in these plans is already known from the original notification to the EC, the additions to the plans, and any amendments or revisions requested by the EC. I expect leaked information prior to formal submission of a national plan to the EC as well as the formal submission of a plan to yield a substantial carbon price response. These two events reveal for the first time the level of reductions proposed by a particular country and as such aid in formulating expectations as to the overall level of allowances which might exist in the system. Depending on whether the proposed plans are viewed as restrictive or loose, the associated price reaction is expected to be, respectively, positive or negative.

Announcements about post-2012 emissions caps, auctioning rules, and the expanding scope of the ETS are suggestive of future scarcity of allowances and are expected to have a positive effect on the price of carbon. On the other hand, the CITL-ITL linkage is seen as negative for the price of carbon, as regulated companies in Europe can now "import" cheaper project-based substitutes for EUAs. The impact on the price of EUAs should be negative. With the advantage of hindsight, I now know that the COP/MOP meetings have not yet negotiated a legally binding post-Kyoto agreement. Hence, I expect announcements from the closing days of these annual conferences to result in carbon price declines.

Hypothesis 1, as well as all other testable hypotheses described in Section 3.3, is based on the premise that the discussed announcements represent genuine news to the market. This implies that there is no information leakage and the market does not anticipate the announcements. It also implies that the announcements are important enough to investors to lead them to revise their expectations about the future carbon price. In short, these announcements are assumed to represent true signal rather than mere noise in the information flow of the carbon market. Violation of any of these assumptions would imply that estimates of event-day returns may be misstated. If announcements are expected by market participants, price reactions on the even day may be understated as information will already be reflected in the price. Also, if the news contains no economic value to investors, prices may not move in a significant manner at all.

H_2: Phase I announcements have no impact on Phase II or III futures prices while Phase II (III) announcements have an impact on both Phase II and Phase III futures prices

Because there will be banking and borrowing of allowances between the second and third trading period of the scheme, the continuity of the Phase II futures prices is ensured. However, inter-temporal transfers of EUAs were forbidden between Phase I and II which resulted in Phase I becoming "a self-contained market that is not related to future caps and political decisions regarding Kyoto" (Hintermann, 2010: p.44). Therefore, I do not expect any of the Phase II or III announcements to have an impact on Phase I futures prices. In contrast, these events will affect both Phase II and III futures prices. I also hypothesize that the impact on the shorter-term futures will be stronger.

H_3: The carbon price is less responsive to institutional announcements following the onset of the financial crisis

I hypothesize that the reaction of the market to institutional disclosures is conditional upon the state of the overall economy. Specifically, during times of economic growth and expanding industrial production the market will be sensitive to announcements about its institutional and organizational framework. This is because covered entities and market participants alike are uncertain as to whether the market is net long or short on allowances. Since this information is revealed only at the annual verification events, announcements during the year will yield a price reaction as market participants update their expectations about the supply-demand balance of allowances. Similarly, during recessionary times the lower level of economic activity implies that regulated companies will be able to comfortably meet their targeted reductions without the need for abatement or purchase of additional allowances. When the market consensus is that of EUA surplus and there is no uncertainty, carbon prices will be less sensitive to institutional announcements.

H_4: An increase in the variance of carbon returns estimated from the relevant[13] futures contract and the option implied volatility are expected after unscheduled institutional announcements. Decreases in both measures of volatility are expected after scheduled announcements.

Among the events analysed in this chapter, only the United Nations' COP/MOP meetings and the annual releases of verified emissions data are scheduled in advance. For the rest of the announcements there is no prior knowledge of when the information will be released. Market efficiency suggests that as new information is released to the market, prices should adjust to a new equilibrium (Fama, 1970). Pricing in the new information will temporarily lead to increases in the volatility of carbon returns when the event is unscheduled. An increase in volatility of carbon futures is consistent with the underlying assumption that this information is market-moving and leads market participants to act on it. If the event is scheduled in advance, volatility is expected to go up prior to the event day as market participant price in the potential outcome of the event. A reduction in volatility is anticipated after the event day, as uncertainty is removed from the market. I use two alternative measures of volatility: variance of returns and Black (1976) implied volatility.

3.4. METHODOLOGY

3.4.1. THE IMPACT OF INSTITUTIONAL ANNOUNCEMENTS ON CO_2 RETURNS

[13] By 'relevant' I mean consistent with Hypothesis 1. For example, announcements related to Phase II should not affect Phase I futures contracts and I do not expect increases in the volatility of returns estimated from these futures.

In order to measure the impact of different announcements on carbon returns, an event study technique is applied. If a market is efficient, new information will be reflected in asset prices as it becomes available (Fama, 1970). Therefore, the significance of an event can be assessed by observing the magnitude of the price changes around the time of the announcement. As seen in Table 3.1, much of the research on the carbon market so far has relied on the use of a constant mean return model as a benchmark against which abnormal returns are estimated**.** This model assumes that the asset's returns are normally distributed with a time-invariant mean and variance (Brown and Warner, 1985). The underlying premise is that future observations will be drawn from the same distribution. To address the high frequency of unscheduled information releases on the market, authors have adjusted the model by trimming the highest and lowest values of the mean carbon return over the estimation period (Mansanet-Bataller and Pardo, 2009; Lepone et al., 2011). The disadvantage of the constant mean return model is that it does not control for changes in energy prices, extreme weather events and economic activity. Thus, abnormal return estimates may be overstated.

The methodology implemented in this chapter is based on the standard OLS regression model. The events whose price effect I aim to measure are introduced in the regression equation via dummy variables and the associated event returns[14] are modelled as the slope coefficients of these dummies (Binder, 1998). I decide in favour of this methodology as it allows me to control for changes in key carbon price drivers and to

[14] The term "event return" (R_e) is used to designate a return above what would be anticipated on a non-event day, whereas the term "abnormal return" may be interpreted as a return above the normal return, holding the level of risk constant. R_e is used in this case as no adjustments for changes in the risk factors have been made. To maintain consistency in the terminology used throughout the chapter, the term "event return" is used with regard to the results of the multivariate regressions in Section 3.6.2.2, even though they explicitly account for the impact of energy prices, stock prices and extreme weather.

obtain more robust estimates of event returns. The empirical analysis is made up of two parts. I first examine the univariate behaviour of carbon prices around the events listed in Table 3.2. I then analyse the same price effects in the context of a multivariate analysis where carbon returns are presented as a function of economic indicators, energy costs and extreme weather. This multifactor model is the focus of the chapter. All regressions are estimated by applying Newey-West standard errors to prevent biases stemming from heteroscedasticity and autocorrelation.

3.4.1.1. Univariate Carbon Price Analysis

Returns associated with the various types of events are calculated with the following regression:

$$\boldsymbol{R_{carbon,t} = \alpha_0 + \sum_{j=1}^{n} \beta_j D_{j,t} + \varepsilon_t} \qquad (1)$$

where $R_{carbon,t}$ is the continuously compounded rate of return for carbon futures on day *t*. $D_{j,t}$ is a dummy variable equal to 1 on the event day and 0 otherwise for all *j*= 1,2…,n sub-categories of events. The intercept α_0 represents the mean daily log-return of carbon during non-event days. The regression coefficients of the event dummies β_j are the calculated mean returns related to the specific events. In other words, they are the daily differences from the mean carbon returns over the non-event days.

The model is estimated for the 1,595 trading days over the period 22/04/2005 – 30/06/2011. The sample is broken down in two ways: 1) building on earlier work, I use the financial crisis to divide the sample, and 2) I use a structural test to detect breaks in the time series of the carbon returns. Two different methodologies are employed to prevent arbitrary choices of subsamples and to provide a test of robustness for the results.

Two breakpoint tests have been employed in the carbon literature to date: the unit root test of Lee and Strazicich (2003) and the Bai-Perron (1998, 2003) method (used by Alberola et al. (2008) and Chevallier (2011b), respectively). With the Lee and Strazicich (2003) test, it is up to the researcher to decide on the number of structural breaks in the model and according to this input, the algorithm decides on the most appropriate partition. Because the Bai-Perron model determines the optimal number of breaks endogenously, and thus the arbitrary selection associated with the Lee and Strazicich (2003) test is avoided, I prefer to follow the Bai-Perron methodology.

The algorithm identifies m points of structural change in a time series which determine $m+1$ separate segments with a different underlying structure. The structural breaks are chosen to minimize the residual sum of squares across all the segments. The Bai-Perron method essentially optimizes the number of separate segments and every new segment is assessed against a Bayesian Information Criterion, the residual sum of squares and an F-test for the marginal break. The test is conducted on the log-return time series of EUA futures contracts which have the nearest December expiration. A minimum of 44 observations is set between the breaks, that is, each regime with unique underlying price dynamics is at least two months long (22 trading days are used as a proxy of a calendar month). This is done to prevent the partitioning of the data into multiple short segments.

3.4.1.2. Multivariate Carbon Price Analysis

A multifactor model can control for market-wide developments and exogenous influences on the carbon prices. I rely heavily on the existing literature in choosing fossil fuel prices, economic indicators and temperature as explanatory variables in the model. The prices of natural gas directly affect carbon prices as power plants switch to carbon-intensive coal-fired electricity generation when gas prices rise (Fezzi and Bunn, 2009; Hintermann, 2010; Declercq et al., 2011). With gas futures prices largely derived from oil prices, oil is another key driver for carbon (Convery and Redmond, 2007; Bredin and Muckley, 2011). The stock market is pro-cyclical by its nature and therefore constitutes a good indicator of the expected health of the economy. Strong economic activity also translates into higher EUA prices as companies produce more and emit more carbon in order to meet the higher demand for their goods (Alberola et al., 2008, 2009; Bredin and Muckley, 2011; Koop and Tole, 2011; Chevallier, 2011a). Therefore equity, as used in Equation 2, measures the anticipated level of future industrial production and the associated emissions levels. Extreme weather indirectly affects carbon prices through its impact on energy demand (Alberola et al., 2008; Fezzi and Bunn, 2009; Bredin and Muckley, 2011). In prior literature, weather has been modelled in different manners in order to capture its impact on the carbon price dynamics. Some of the alternative specifications include: extreme weather days measured against a pre-specified temperature threshold (Fezzi and Bunn, 2009) or proxied by the 95% upper and lower quintiles from the temperature series (Alberola et al. 2007, 2008). Squared temperature (Gerlagh and Liski, 2012) and the magnitude of high deviations from seasonal mean temperatures (Alberola et al. 2007, 2008) are other weather variables used by researchers.

The multifactor regression model I use takes on the following form:

$$R_{carbon,t} = \alpha_0 + \theta_{oil} R_{oil,t} + \theta_{gas} R_{gas,t} + \theta_{equity} R_{equity,t} + \theta_{cold} D_{cold,t} + + \theta_{hot} D_{hot,t} + \sum_{j=1}^{n} \beta_j D_{j,t} + \varepsilon_t \quad (2)$$

where $R_{carbon,t}/R_{oil,t}/R_{gas,t}/R_{equity,t}$ is the continuously compounded rate of return for carbon/oil/gas/stock market on day t. D_{hot} and D_{cold} are dummy variables which take on the values of 1 on extremely hot and cold days and 0 otherwise.

The main assumption underlying OLS analysis is that the regressors are exogenous to the dependent variable. To prevent an endogeneity problem, I limit the use of mutually interactive regressors in Equation 2. For example, electricity is often quoted as a carbon price driver (Chevallier, 2009; Fezzi and Bunn, 2009). I capture its impact on carbon by using extreme weather events since it is through the demand for electricity that temperature affects EUA prices. Some researchers have used clean dark[15] and spark[16] spreads as well as the fuel switching EUA price[17] in addition to the absolute prices of fossil fuels as carbon price drivers (Alberola et al., 2008; Bonacina et al., 2009; Koop and Tole, 2011; Bredin and Muckley, 2011). In addition to my concerns about introducing such correlated variables in the analysis, I question the relevance of these variables as EUA price determinants altogether. For instance, a switch between energy generation sources may occur even though carbon price may be below its "switch" level, if energy demand is so high that both coal- and gas-fired units need to be running to meet the demand (Delarue and D'haelseleer, 2007). A problem with the use of

[15] Clean dark spread is the difference between the price of electricity and the price of coal used to generate that electricity, corrected for the energy output of the coal plant (Tendances Carbone, 2011).
[16] Clean spark spread is calculated in the same manner but refers to a gas-fired power plant instead.
[17] The fuel switching price is the price of carbon which makes a plant indifferent between using gas- or coal-fired plants for generating electricity given a certain assumed efficiency of the plant.

spreads as carbon price drivers is that due to their different efficiencies, power plants will switch from coal- to gas-fired units at different EUA prices. The clean spreads used in most studies rely on assumptions about the average plant size and the average plant efficiency and grossly over-simplify the analysis by assuming homogenous plants across countries.

3.4.2. THE IMPACT OF INSTITUTIONAL ANNOUNCEMENTS ON CO_2 VOLATILITY

Similar to earlier studies, a Brown-Forsythe (1974) robustness test for variance homogeneity and a non-parametric sign test are used to address the issue of whether the variance of carbon returns changes before and after the announcements. The Brown-Forsythe (1974) procedure is based on the ANOVA statistics applied to absolute deviations from the corresponding median. To maintain comparability with earlier literature (Mansanet-Bataller, 2009; Lepone et al., 2011) I look at a 10-day estimation period and compare the variance of carbon returns 5 days before the announcement and the variance over the announcement day and the following 4 days. Confounding events are not likely to bias the results because the median as an estimate of central location in the Brown-Forsythe test is not affected by extreme values (Mansanet-Bataller and Pardo, 2009) [18]. The sign test is constructed in a similar fashion. The advantage of such a non-parametric test is that it does not require normality in order to be properly specified.

[18] In a robustness test whose results are not reported here for purposes of brevity, I apply restrictive criteria and use only those announcements which have no other confounding events in the whole 10-day estimation window. The sample of events is substantially reduced but the results are quantitatively and qualitatively identical.

To test for changes in the option implied volatility before and after information releases, I estimate Black (1976) implied volatility as described in Section 2.4.3 of Chapter 2. Implied volatility is derived from options with the nearest December expiration. Only options with at least 10 days left until maturity on the event day are considered (Donders and Vorst, 1996). In addition, all options in which no trading takes place during the entire 10-day period around a given announcement are discarded from the sample. For example, during the second half of 2007, the near December expiration futures were effectively worthless and no trading in the options for these futures took place due to the restrictions on allowance bankability between Phase I and II. In addition, because options on the carbon futures contracts were launched in late October 2006, I cannot assess the impact of NAP I announcements on the option implied volatility. Following earlier literature (Donders and Vorst, 1996; Donders et al., 2000; Kim, 2008), the following regression model is estimated:

$$\boldsymbol{\sigma_{i,t} = \sum_{t=-5}^{4} \beta_i D_{i,t} + \varepsilon_{i,t}} \tag{3}$$

where $\sigma_{i,t} = \sigma_{i,t}^{implied} - \bar{\sigma}_i^{implied}$ is the deviation of implied volatility $\sigma_{i,t}^{implied}$ observed on day t for announcement i from the average implied volatility $\bar{\sigma}_i^{implied}$ for the same announcement over the entire 10-day period. $D_{i,t}$ is a binary variable equal to 1 for observations on day t and 0 otherwise. A statistically significant slope coefficient β_i indicates a statistically meaningful change in implied volatility.

3.5. DATA

3.5.1. ANNOUNCEMENT DATA

The announcement data is manually collected from several sources. These include the official websites of the European Commission and the UNFCCC, the Community Independent Transaction Log, and lastly, the Point Carbon newswire. By using different sources, I am able to identify the earliest date at which new information reaches the market. Event days (*t=0*) are defined as those days on which news is released to the public. 283 announcements are identified over the period 22/04/2005 – 30/06/2011. An announcement is retained in the final sample if all of the following conditions are met. First, there can be no same-day announcements which belong to different categories. For example, on December 15th 2006 the Netherlands notified the EC of additional information to their already submitted Phase II NAP while Italy submitted its plan for the first time. Because the impact of each announcement cannot be measured accurately, December 15th is not considered as an event day. The second criterion which I impose aims to improve the robustness of the event study results. Events which have other announcements on the previous or following day are removed in order to minimize confounding influences. This reduces the final sample to 87 observations, as shown in Table 3.2. The announcements are classified into eight general categories and several subcategories are identified within each category. This finer sub-classification ensures that events with a potentially strong impact on carbon prices are not combined with events which may not necessarily yield abnormally positive or negative returns, thereby washing away the significance embedded in the former.

One caveat to the analysis is that because of the restrictive selection criteria and the high frequency of announcements, several important events are dropped from the sample. Some of these include: 1) the release of verified emissions data for 2006 is omitted because it coincides with the Austrian NAP II endorsement by the EC and the notification of additional information to the EC by Hungary, 2) on November 29th 2006 the EC rejected 9 Phase II NAPs and accepted only one plan, 3) on January 15th 2007 the withdrawal of the Cypriot NAP II coincided with the official notification of NAP II to the EC by Austria, and 4) on October 26th 2007 the EC approved the Phase II NAPs of Germany, Romania and Bulgaria, and also announced that it had come to an agreement with the countries in the European Economic Area on linking their respective emissions trading systems, an event falling under the category of announcements labelled “Scope of the EU ETS”.

To ensure that the results don’t change materially after removing these events from the sample, all the event study regressions are also conducted with the larger set of 217 events. The results of these regressions are arguably less robust because of the confounding influences of events which take place on consecutive days. Mainly for comparison with prior literature I report the results in Appendix 3B. In their event studies, both Mansanet-Bataller and Pardo (2009) and Lepone et al. (2011) use all available events, without imposing any restrictive conditions in order to minimize biases.

3.5.2. Carbon return-generating model

Details of the explanatory variables used in Equation 2, their functional currencies and contract specifications can be found in Table 3.3 overleaf. The carbon price is based on EUA futures prices quoted on the European Climate Exchange (ECX). The oil price is based on the daily Brent Oil Front Month futures contract traded on the Intercontinental Commodities Exchange (ICE) platform. The natural gas price is based on the daily Month Ahead Forward contract also from the ICE. To transform all the price series in the same currency (Euro), exchange rate data from the European Central Bank is used. The Dow Jones Euro Stoxx index is used as a measure of the expected level of economic activity. The DJ EuroStoxx 600 index is chosen over the EuroStoxx 50 (used, for example, by Bonacina et al., 2009) because a broad-based stock market is more representative of anticipated growth prospects in the European economy.

To account for the importance of weather as a price driver in the carbon market, I follow the methodology of Koop and Tole (2011). A European Temperature Index is estimated over the period 01/1985 – 12/2004 as the weighted average of temperatures measured in countries covered by the EU ETS. The weight given to a country in the composition of the index is proportional to that country's population. Temperature deviations from the historic mean are calculated for any given month and days with extremely hot or cold weather are modelled as dummy variables in the regression. Data on the mean daily temperatures are taken directly from the European Climate Assessment Dataset (Klein Tank et al., 2010). Data on the population is reported by Eurostat and taken from Datastream. Details on the methodology used in constructing the temperature variables can be found in Appendix 3A.

Table 3.3 Description of the variables and data sources

Variable	Description
EUA	ICE ECX EUA Futures (Euro/ tonne of CO_2) The price of carbon is measured as the December expiration EUA futures contracts. Source: European Climate Exchange
Oil	ICE Brent Crude Futures – North Sea (U.S. dollars/ barrel) Oil price is measured as the daily price of the month ahead Brent Crude futures negotiated on the Intercontinental Commodities Exchange (ICE). The Brent Crude futures contract with a North Sea hub is a deliverable contract based on EFP delivery with the option to settle in cash. Source: Intercontinental Commodities Exchange (ICE)
Natural Gas	ICE Natural Gas 1 Month Forward (UK Pence/100000 British Thermal Units) Natural gas is measured as the daily price of the 1 Month Forward contract from the Intercontinental Commodities Exchange (ICE). The ICE Natural Gas contract is denominated in UK Pence per 100000 British Thermal Units. Source: Datastream
Equity	Economic activity is proxied by the performance of the Dow Jones Euro Stoxx index (DJ Euro Stoxx). Prices are denominated in euros. Source: Datastream
Weather	European Climate Assessment & Dataset website, available at http://eca.knmi.nl/. See Appendix 3A for details.
Events	PointCarbon; the official websites of the European Commission and the UNFCCC; The Community Independent Transaction Log

3.6. EMPIRICAL RESULTS

3.6.1. UNIVARIATE CARBON PRICE ANALYSIS

Prior to any econometric analysis, I conduct a preliminary test to confirm that the selected event categories are in fact informative to the carbon market. The extent to which an announcement is value-relevant can be inferred by the magnitude of the price response it elicits. I anticipate that the events from Figure 3.1 will lead to large changes in carbon prices and traded volumes. Following Cutler et al. (1989) and Ryan and Taffler (2004), I identify the hundred days with the largest changes in prices and trading volumes of nearest-to-maturity carbon futures contracts. These days are then matched with the events of interest. Panel A in Table 3.4 demonstrates that 24% (19%)

Table 3.4 Announcement categories, price changes and trading volume increases
This table describes the 100 largest changes in prices and trading volumes of nearest-to-expiry December EUA futures contracts over the period 22/04/2005 – 30/06/2011. A price change is measured as i) log-return, and ii) absolute difference between the opening-to-closing settlement prices on any given day.

Panel A. Proportion of significant changes in prices and volumes matched with announcements related to the institutional framework of the EU ETS.

	Price Change		**Trading Volume Change**
	Log-returns	Absolute price difference (in €)	
All events*	24%	19%	11%

*These are all events without any restrictions for the event day to have no other information event on the day before or after the data release

Panel B. Overview of the announcement categories with a significant impact on the prices and trading activity of EUA futures. The number of announcements in each category is expressed as a percentage of all announcements resulting in one of the top 100 largest price changes or trading volume increases.

Event category	**Log-return Change**	**Absolute price difference (in €)**	**Absolute Volume**
NAP I: Notification of additional information	4.17%		
NAP I: Acceptance	8.33%	10.53%	
NAP II: Leaked information before formal release	8.33%	15.79%	
NAP II: Notification to the EC	8.33%		9.09%
NAP II: Notification of additional information	16.67%	21.05%	
NAP II: Notification of amended plan	4.17%		
NAP II: Additional information to amended plan	12.50%		
NAP II: Acceptance	8.33%		
NAP II: Rejection			9.09%
NAP II: Announcements after official EC decisions			9.09%
Phase III: Emissions caps	12.50%		9.09%
Phase III: Auctioning rules			9.09%
Scope	8.33%	21.05%	45.45%
Verification 2005	4.17%	21.05%	
Verification 2007		5.26%	
Verification 2008	4.17%		
Other announcements: UK		5.26%	
CERs			9.09%

of the largest price changes (as measured by log-returns and absolute price differences) and 11% of the largest trading volume changes are associated with the announcements analysed in this chapter. This suggests that there is a strong link between market reactions and the disclosure of information related to the ETS institutional structure. Panel B shows the percentage of observed price changes and trading volume increases which can be attributed to each of the announcement categories. All of the announcement categories are represented which suggests that the categories are well-specified and the announcements are important to the market.

The two carbon price time series examined in this chapter are labelled "Interphase EUA futures" and "Intraphase EUA futures". The term Interphase futures refers to contracts traded in the current phase of the EU ETS with underlying contracts which call for the delivery of EUAs in the next phase of the scheme. Intraphase EUA futures, on the other hand, are the nearest-to-maturity contracts with December expiry. To illustrate, on February 22nd, 2006 (Phase I of the EU ETS), the corresponding interphase futures contract has a December 2008 expiry while the intraphase futures contract has a December 2006 expiry. Continuously compounded returns are used so that $R_{carbon,t} = ln(P_{EUA,t} / P_{EUA,t-1})$ where $P_{EUA,t}$ is the settlement price of the EUA futures contract negotiated on the European Climate Exchange at time *t*. Trading of EUA futures contracts on the European Climate Exchange started on April 22nd, 2005 which marks the first day of the sample in this chapter. The dataset covers the period 22/04/2005 – 30/06/2011. The Augmented Dickey-Fuller test confirms the lack of a unit root for the intra- and interphase EUA futures at the conventional test sizes.

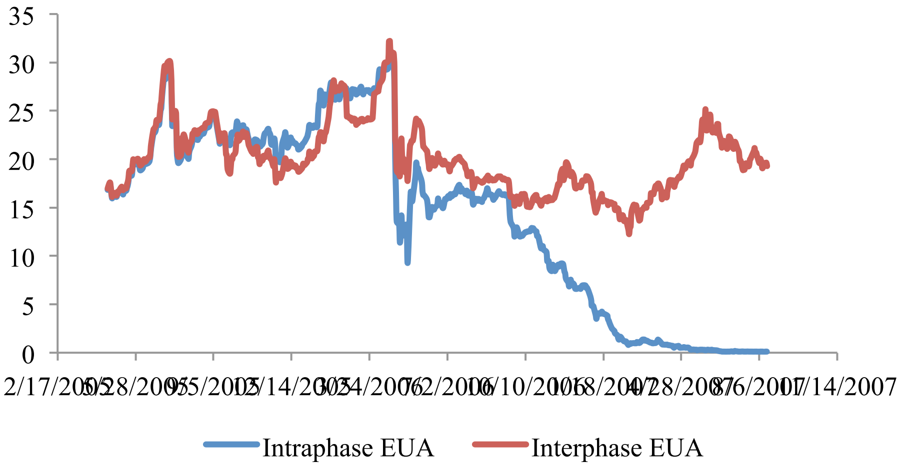
3.6.1.1. The financial crisis and its impact on the carbon price dynamics

Putting a finger on the exact date when the financial crisis began has proven difficult for both academics and practitioners. Some trace its onset to the Lehman Brothers bankruptcy in September 2008, while others argue it started much earlier in January 2007. I follow prior work in the carbon literature (Mansanet – Bataller et al., 2010; Chevallier, 2011c) in identifying the start of the financial crisis as the first reduction in interest rates by the U.S. Board of Governors of the Federal Reserve System on August 17th, 2007. The dataset is then divided into pre- and full-crisis subsets, covering the periods 22/04/2005 – 16/08/2007 and 17/08/2007 – 30/06/2011 respectively. The price effect of the events from Table 3.2 is examined during the two subsamples on intraphase as well as interphase EUA futures.

A. Pre-crisis subsample (22/04/2005 – 16/08/2007)

Figure 3.2 graphically presents the price development of intra- and interphase EUA futures contracts over the period. Futures are rolled over a month before their expiration date. A dichotomy between the two price series is observed following the disclosure of verified emissions for 2005 which took place in mid-May, 2006. The price decline of Phase II futures is quickly followed by a recovery, while the prices of Phase I futures trend towards zero until the end of the pre-crisis dataset. This results from the fact that banking and borrowing of carbon allowances were forbidden between Phase I and II of the ETS.

Figure 3.2 Pre-crisis subsample
The figure shows the price development of near maturity and near phase EUA futures contracts over the period 22/04/2005 – 16/08/2007.



The results of Equation 1 for the pre-crisis subsample are reported in the first five columns of Table 3.5. In terms of announcements related to Phase I NAPs, several observations need to be made. At the time these announcements were made, Phase II futures were quoted on the ECX but there was still no trading in them. Although the impact of all three NAP I announcements on interphase futures shows up as statistically significant, the results carry no economic meaning[19]. The notification of additional information regarding an already submitted plan has a statistically significant positive impact on the returns of intraphase EUA futures contracts. This reflects the bullish sentiment of investors and implies that the proposed changes to the plan are viewed as restrictive by the majority of market participants. The acceptance of Phase I NAPs (which refers to the acceptance of the Greek plan on June 20th, 2005) also has a statistically significant positive impact on the returns of intraphase EUA futures

[19] Quoted Settlement Prices (QSPs) are used by the European Climate Exchange to interpolate QSPs for those contract months for which no quoted prices are received from market participants of for which no bid or offer quotes are made. The QSP is estimated as an average of quoted prices for specific contract months provided daily by market participants and is determined by a designated Market Supervision Official at his discretion. A description of the methodology for determining Unofficial Settlement Prices is obtained via personal communication with the headquarters of the ECX.

contracts. As hypothesized, NAP rejection is associated with statistically meaningful positive event returns for Phase I EUA futures. This category of announcement is represented by the rejection of the British plan by the EC on February 22nd, 2006. It was the plan's second rejection, even though the Court of First Instance had already ruled in favour of the UK and against the EC's original restrictive decision not to allow the UK an increase in allowances. Further reductions in the proposed NAP imply a greater scarcity of EUAs in the future, hence the positive market response following the announcement.

By the time NAP II announcements started to be released, trading in Phase II futures had also started. Information releases before a formal submission to the EC are found to have no impact on interphase futures and a significant negative impact on intraphase futures (which is distinguishable from zero only at the 10% level). As expected, formal notifications of Phase II NAPs to the EC do not affect Phase I futures but significantly affect the price of Phase II futures. The event return is negative, suggesting that the proposed NAPs II are seen by the market as too generous. Notifications of additional information about the original plans submitted to the EC have no statistically significant impact. It is possible that the proposed changes are immaterial relative to the total number of allowances or that the additional information refers to elaborations of the original plan and that no changes in the terms of projected reductions are discussed.

Notifications of additional information to amended Phase II plans have no impact on the development of Phase I EUA futures prices. The impact on Phase II futures is, however, both significant and negative. This confirms yet again that the proposed changes are viewed as insufficient to sustain the scarcity of EUAs during the second trading period of the scheme. The acceptance of Phase II NAPs does not elicit a significant market reaction from either the intra- or the interphase EUA futures contracts, which suggests that all information has been assimilated in the prices. Being already familiar with the additional information and amendments made to the initial plans, it would seem that market participants expected the EC to eventually accept the NAPs and so no surprise takes place.

As for non-NAP announcements during the pre-crisis period, information releases about the ETS expansion are found to elicit positive market responses in both carbon price series. This most likely suggests that market participants factor in future increases in demand for EUAs, as well as better functionality, and improved depth and liquidity of the carbon market. Since all the scope announcements are related to proposed expansions of the scheme in Phase II, the statistically significant event return of intraphase futures is inconsistent with the ban on inter-temporal transferability of allowances between the first two trading periods of the EU ETS. The COP/MOP event has a significant negative impact on both EUA futures. The reason for the negative reaction following the 2006 meeting in Nairobi, Kenya most likely reflects the market's disappointment with the inability of international leaders to reach a legally binding agreement about the long-term future of the carbon market in a post-Kyoto world.

The disclosure of verified emissions for 2005 is found to have caused significant positive event returns for both intra- and interphase EUA futures contracts. In fact, the release of the emissions data is the event which has brought about the largest event returns: β_{ver05}= 0.4940 (0.1865) for Phase I (II) EUA futures. Information about the 2005 verified emissions was scheduled to be disclosed publicly on the platform of the

Table 3.5 Univariate analysis: before and during the financial crisis

The table reports the regression results of Equation 1. The sample is split into pre-crisis (22/04/2005 - 16/08/2007) and full-crisis (17/08/2007 - 30/06/2011) subsamples. The dependent variable is: 1) log-return of nearest-to-expiry EUA futures contracts, 2) near-phase EUA futures. Robust Newey-West HAC standard errors are used. The corresponding t-statistics are reported in parentheses. Event return is denoted as R_e and non-event return – as R_{ne}.

	Pre-crisis subsample				**Full-crisis subsample**			
Event	**Intraphase futures R_e**		**Interphase futures R_e**		**Intraphase futures R_e**		**Interphase futures R_e**	
Intercept (**R_{ne}**)	-0.0093	(-3.77)	0.0000	(-0.01)	-0.0012	(-0.91)	-0.0005	(-0.65)
NAP I: Notification of additional information	0.0407*	(11.46)	0.0311* †	(10.88)				
NAP I: Acceptance	0.0777*	(31.55)	0.0672* †	(51.09)				
NAP I: Rejection	0.0075**	(3.03)	-0.0186* †	(-14.13)				
NAP II: Leaked info before formal submission	-0.0206***	(-1.8)	-0.0166	(-1.57)	0.0160*	(12.47)	0.0139*	(19.56)
NAP II: Notification to the EC	-0.0004	(-0.07)	-0.0040***	(-1.87)	-0.0294*	(-22.94)	-0.0302*	(-42.43)
NAP II: Notification of additional information	0.0080	(0.25)	-0.0071	(-0.7)	0.0012	(0.91)	0.0061*	(8.64)
NAP II: Notification of amended plan					0.0101*	(3.11)	0.0065*	(3.59)
NAP II: Additional information to amended plan	-0.0401	(-0.39)	-0.0136*	(-4.96)				
NAP II: Acceptance	-0.0154	(-0.75)	0.0058	(0.5)	-0.0202	(-0.93)	0.0004	(0.14)
EC announcement after its formal decision					-0.0143	(-1.26)	-0.0142	(-1.61)
Phase III: Emissions caps					0.0140	(1.58)	0.0119	(1.53)
Phase III: Auctioning rules					0.0181*	(2.64)	0.0153*	(2.71)
Scope	0.0409*	(3.62)	0.0152**	(2.34)	0.0013	(0.11)	-0.0079	(-1.44)
Verification 2005	0.4940*	(200.72)	0.1865*	(141.9)				
Verification 2007					0.0404*	(31.52)	0.0396*	(55.73)
Verification 2008					0.0404*	(31.55)	0.0241*	(33.85)
Verification 2009					0.0212*	(16.58)	0.0182*	(25.63)
Other announcements: UK					-0.0036	(-0.36)	0.0007	(0.09)
Other announcements: Germany					0.0192*	(14.99)	0.0171*	(23.99)
CITL – ITL linkage					0.0150	(1.6)	0.0168**	(2.08)
CERs					0.0042	(1.38)	0.0010	(0.35)
COP/MOP	-0.0094*	(-3.82)	-0.0131*	(-9.93)	-0.0010	(-0.33)	-0.0013	(-0.53)
R-squared	11.95%		7.63%		0.79%		1.84%	
Adjusted R-squared	10.29%		5.89%		-0.94%		0.14%	

*, **, *** refer to significance at the 1%, 5% and 10% level respectively

† indicates that although a price is quoted on the ECX, trading in these futures hasn't started yet

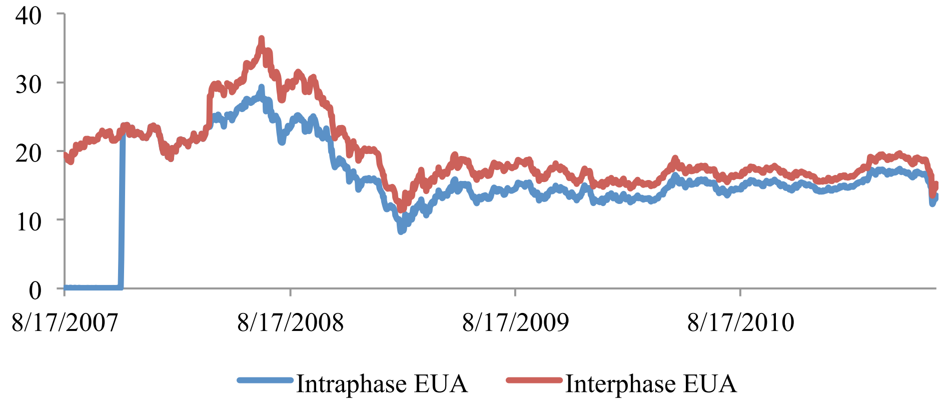
Community International Transactions Log (CITL) on May 15th 2006. On April 24th 2006 the Netherlands, the Czech Republic and France reported fewer emissions than expected in the first year of emissions trading. Three weeks ahead of the scheduled release date, market participants already knew that, contrary to expectations of shortages, there were excess EUAs in the system. The carbon price collapsed immediately. Because other announcements also took place on the day on which verified emissions data for 2005 was leaked, this event had to be removed from the dataset. Carbon prices temporarily increased following the official data release as it became clear that the oversupply of allowances was smaller than anticipated. Therefore, the seemingly contradictory positive market reaction on May 15th is a reversal of the initial overreaction to the expected excess EUAs (Mansanet-Bataller and Pardo, 2009). Mansanet-Bataller and Pardo (2009) report event returns of 51.11% on the day of official verified emissions data release. While such event return in the intraphase futures contract appears to be justifiable, the reaction observed in Phase II futures suggests that market participants are not able to accurately assess the implications of inter-temporal banking and borrowing of allowances. Because allowances from Phase I cannot be banked into Phase II, the price of futures contracts with expiry in 2008 should be unaffected by the 2005 verified emissions disclosure.

B. Full-crisis subsample (17/08/2007 – 30/06/2011)

Figure 3.3 depicts the price development of intra- and interphase EUA futures contracts over the full-crisis period. A short-lived rally in early 2008 was quickly replaced by a steady price decline against the backdrop of a growing sovereign debt crisis in Europe.

2009 and 2010 were marked by fairly stable EUA prices, within the narrow range of €12-15 per tonne of CO_2.

Figure 3.3 Full-crisis subsample
The figure shows the price development of near maturity and near phase EUA futures contracts over the period 17/08/2007 – 30/06/2011.



The results of Equation 1 for the full-crisis subsample are reported in the last four columns of Table 3.5. The first thing to note is the low explanatory power of the model after the onset of the financial crisis: the coefficient of determination is 0.79% (1.84%) for the intra-(inter) phase EUA futures and the adjusted R-squared is in fact negative for the intraphase futures[20]. This finding is in sharp contrast to the pre-crisis results where the adjusted R-squared is 10.29% (5.89%), respectively. The decline in the coefficients of determination implies that less of the variation in carbon prices can be attributed to institutional announcements. This result confirms Hypothesis 3 that following the onset of the financial crisis the carbon market has become less responsive to announcements regarding its institutional set-up. As noted in Section 2.6, sluggish industrial production left many covered companies with excess allowances. Covered

[20] Similarly low R-squared and negative adjusted R-squared are reported in Lepone et al. (2011) as well: adjusted R-squared in the event study regression with oil, gas and event dummies for intraphase EUA futures contracts over the period 01/02/2006 – 31/12/2008 is -0.013012.

companies realized that they will face no real shortages and no internal abatement will have to take place in order for reduction targets to be met. Due to the availability of banking between Phase II and III of the ETS, the common view was that the carbon market would be net long overall even in the post-2012 period as the excess allowances are transferred into Phase III[21]. In the context of known excess of EUAs in the system, investors appear to be more likely to dismiss announcements about changes in the policy and the ETS institutional set-up.

Information releases prior to a plan's official submission to the EC have a positive and significant impact on both intra- and interphase futures contracts. Interestingly, before the financial crisis, leaked information was shown to negatively affect carbon prices. This differentiated reaction to informal data releases may be due to the different economic context of the announcements. Against the background of the spiralling financial crisis and the evident willingness of certain national leaders to temporarily put climate action on hold[22], early announcements about Phase II NAPs seem to have been welcomed by the market. At least, it was seen that the scheme would continue to function and would not be shut down due to economic difficulties. As expected, the impact on longer maturity EUA futures (β=0.0139) is smaller than the impact on futures with a shorter time to expiry (β=0.016).

[21] Carbon Trade Watch, "EU Emissions Trading System: failing at the third attempt." This study shows that there are some 970 million excess allowances from the second trading period of the ETS which can be transferred into the third phase. This means that polluters "need to take no action domestically until 2017." Available at: http://www.carbontradewatch.org/downloads/publications/ETS_briefing_april2011.pdf

[22] For instance, the Polish prime minister was keen to ease the pledged reduction commitments as these were seen to stall economic growth in already financially challenged countries. As noted by Christopher Booker in his book *The Real Global Warming Disaster* (2010), " At the meeting in Posnan in December which was meant to plan the successor of Kyoto, the Italians and the Poles were now threatening to veto the Copenhagen proposals on the grounds that the economic crisis made them unaffordable".

The actual notification of a NAP II to the EC is associated with a negative market reaction (regression coefficients of -0.0294 and -0.0302 for intra- and interphase EUAs, respectively). This infers that market players considered the proposed NAPs inflated and corrected the high expectations they had built up following the leaked information. The stronger reaction of the interphase futures suggests a concern for the longer-term viability of the ETS as excess allowance in Phase II can be transferred into Phase III of the scheme.

As expected, additions and amendments of the originally submitted plans are associated with positive event returns as downward revisions of EUA allocations are factored into the carbon price. Notifications of amended NAPs II have a statistically significant and positive coefficient on both intra- and interphase EUA futures contracts (0.0101 and 0.0065, accordingly). Announcements after the formal decision of the EC on a NAP II did not meaningfully affect carbon prices. As information about all the changes and reviews of the original plans is incorporated into the prices by the time the EC makes a formal announcement, it is no surprise that the actual acceptance of the Phase II NAPs is not a market-moving event. This result differs from the findings of Rotfuβ et al. (2009) who conclude that plan acceptances lead to abnormal reactions. The difference may be due to the fact that Rotfuβ et al. (2009) employ high-frequency data and also use Phase I allocated allowances as a proxy for expected Phase II reduction targets. The authors do not account for the fact that investors have updated their expectations following notifications of additional information and amendments to the plan.

I find a positive yet insignificant impact of announcements related to post-2012 emission reduction targets on the carbon price development. News in this category include the conditional agreement of the EU to a 20-30% target for the Copenhagen accord; the downward EC revision of the 2013 ETS emissions cap by 2.4%; the MEPs' vote to urge European leaders to agree to a legally-binding goal to cut emissions 30 per cent of 1990 levels. Announcements related to the scope of the ETS also yield positive but insignificant market reactions. At the same time, news related to the adoption of new auctioning rules during the post-2012 trading period are found to have a significant positive impact on both intra- and interphase EUA futures.

With regards to the impact of verification events on the carbon price dynamics, all three events (2007, 2008 and 2009 emissions data releases) are found to cause positive event returns for both EUA futures prices. In fact, the disclosure of emissions during 2007 and 2008 are the two events with the greatest impact on carbon prices: $\beta_{VER'07}$=0.0404 (0.0396) and $\beta_{VER'08}$= 0.0404 (0.0241) for the intra-(inter) phase EUA futures. The positive market responses indicate that the market expected a larger excess of EUAs than was the case in reality.

The category of events labelled "Other announcements: UK" is not found to lead to significant event returns for carbon prices. On the other hand, the German announcement that their targeted emission cut was to be increased to 55% by 2030 and 70% by 2040 creates statistically significant positive event returns in both carbon price series (the regression coefficients for "Other announcements: Germany" are 0.0192 and 0.0171 for the Phase II and III EUA futures, respectively). These results confirm that, as a key player in the EU ETS, Germany's carbon policy affects the price dynamics of EUAs.

Announcements about carbon offsets generated under the Kyoto Clean Development Mechanism and their usability for ETS compliance purposes do not meaningfully affect the price of carbon during the times of the financial crisis. I don't find this illogical as in the environment of known EUA oversupply due to lower industrial production, covered entities will comfortably meet their targets even without seeking EUA substitutes for compliance purposes.

And, lastly, COP/MOP events have a negative yet insignificant impact on EUA futures prices. A possible explanation for the insignificant results is that the outcomes of the meetings and the failure to agree on a Kyoto successor were largely anticipated by the market. The carbon market sentiment surveys conducted by the International Emissions Trading Association (IETA) in 2009, 2010 and 2011[23] support this view. IETA reports that in 2009 only 52% of the respondents believed that a legally-binding post-Kyoto agreement would not be reached at COP 15 and would be postponed until COP 16. In 2010 60% believed that an agreement would be delayed until later in the following year. In 2011 the number of survey respondents who believed the agreement would be postponed yet again had grown to 79.2%.

In brief, the results from the pre-crisis and full-crisis univariate analysis suggest that investors respond to market-sensitive information as it becomes available but the magnitude of the market reactions tends to be fairly small (save for the verification events). As per Hypothesis 1, announcements suggestive of increase (decrease) in EUA

[23] IETA 4th Carbon Market Sentiment Survey: http://www.pwc.com/en_GX/gx/sustainability/assets/ieta-reporting.pdf
IETA 5th Carbon Market Sentiment Survey: http://www.pwc.co.uk/en_UK/uk/assets/pdf/ieta-2010-survey.pdf
IETA 6th Carbon Market Sentiment Survey: http://www.ieta.org/assets/Reports/ieta_6th_ghg_market_sentiment_survey.pdf

supply (demand) tend to be associated with negative event returns while announcements suggestive of decrease (increase) in EUA supply (demand) tend to be associated with positive event returns. The reported market reactions, however, reveal that on many occasions investors have failed to account for the different rules on inter-temporal allowance transferability across trading periods. As a result, abnormal reactions are reported when there should be none. The observed investor behaviour is inconsistent with Hypothesis 2. Lastly, the results lend support to the view that market responsiveness to institutional announcements has declined following the onset of the financial crisis (Hypothesis 3), as evidenced by the significant decrease in carbon variance attributed to such announcements during the full-crisis subsample.

As a final note, before proceeding with the structural break tests, it is perhaps worth highlighting that developments in the carbon market seem to be bearing a striking resemblance to the decline in activity experienced by the United States' SO_2 trading scheme (the so-called Acid Rain Program). After a decade of successful sulphur trading, the price of SO_2 permits began to fall (Chan et al., 2012). Low-sulphur coal, oil and natural gas had all dropped in price, facilitating reduction of sulphur emissions in excess of what had been foreseen by regulatory authorities. Because allowances in the SO_2 market were mostly given away for free, as in the EU ETS, excess allowances flooded the market pushing sulphur prices down and distorting the incentives of companies to further abate internally. Regulatory uncertainty caused by the potential implementation of pollution control requirements at the firm-level exerted further downward pressure on the already depressed prices[24] (Burtraw and Szambelan, 2009). The inflexibility of the scheme in adapting reduction targets by removing the excess allowances kept the marginal cost of compliance artificially low. The EU ETS seems to be on the same path – over-allocation of allowances in Phase I was followed by excess allowances caused by lower-than-expected industrial production in the aftermath of the financial crisis. On-going regulatory uncertainty about the continuation of the scheme, the reduction targets and the rules about allocating EUAs exacerbate the situation. The obvious question is whether the decline of the sulphur market will be followed by a similar decline in the EU ETS because regulatory authorities have not learned from the mistakes of the former.

3.6.1.2. Structural break test

Building on the work of Chevallier (2011b), I employ the Bai-Perron (1998, 2003) methodology in order to identify structural breaks in the price series of EUA futures contracts. A combination of the Bayesian Information Criterion (BIC) and the residual sum of squares (RSS) is employed to determine the optimal number of breaks in the data. As seen in Table 3.6, the BIC is minimized for two breaks and the RSS shows little improvement after the second break. Therefore, two points of structural change are used in the time series which correspond to the following dates: December 27th, 2006 and June 22nd, 2007. The three regimes suggested by the Bai-Perron methodology are: 25/04/2005 – 26/12/2006; 27/12/2006 – 21/06/2007 and, finally, 22/06/2007 – 30/06/2011. These subsamples relate closely to the pre-crisis/full-crisis split used in

[24] These new regulatory pollution controls were eventually approved. The Clean Air Interstate Rule of 2005 (www.epa.gov/cair) and the Cross-State Air Pollution Rule of 2011 (www.epa.gov/airtransport) both include installation-level requirements on the allowable level of sulphur emissions.

Section 3.6.1.1. The first two subsamples span the pre-crisis times and the third subsample almost overlaps with the onset of the financial crisis.

Unfortunately, the structural breaks identified in this chapter cannot be directly compared to those of Alberola et al. (2008) and Chevallier (2011b). The former employ a different methodology altogether and cover a much smaller time span. The latter uses 22 as the minimum number of observations per segment and examines only a subset of the data covered in this chapter. Nevertheless, it is useful to note the breaks they identify. Over the period 01/07/2005 – 30/04/2007, Alberola et al. (2008) find breaks on April 25th 2006 and May 15th 2006 when the Lee and Strazicich test with two breaks is run. October 2006 is reported as a break when the same test is run for one structural break in the time series. Employing the Bai-Perron algorithm, Chevallier (2011b) detects three breaks over the period 09/03/2007 – 31/03/2009. These are May 28th 2007, December 30th 2008 and February 11th 2009.

Table 3.6 Bai-Perron RSS and BIC output (Univariate analysis)

Number of breaks	0	1	2	3	4	5
RSS	3.72	3.69	3.60	3.59	3.56	3.54
BIC	-5102.69	-5100.59	-5123.54	-5114.26	-5112.94	-5103.81

*RSS = Residual Sum of Squares; BIC = Bayesian Information Criterion
**BIC is minimized for two breaks and RSS shows little improvement after the second break.

A. Subsample 1 (22/04/2005 – 26/12/2006)

The period from 22 April 2005 until 26 December 2006 is a subset of the pre-crisis time period which was examined in Part A of Section 3.6.1.1. Therefore, the findings in this section are expected to be quantitatively and qualitatively similar to the findings for the pre-crisis subsample. Results of the univariate regression model for all Bai-Perron subsamples are reported in Table 3.7. To keep the size of this chapter manageable, I only briefly note the results where they are identical with the pre-crisis subsample and focus on the differences between the results found in Tables 3.5 and 3.7.

Similar to the pre-crisis subsample, notifications of additional information to Phase I NAPs and the official EC endorsement of these plans are found to have a significant and positive impact on the prices of EUA futures contracts. Leaked information about Phase II NAPs meaningfully affects only the prices of Phase I futures.

Unlike the pre-crisis subsample, an insignificant negative market reaction is documented after official notifications of Phase II NAPs to the EC and a significant negative reaction after additions are made to these plans. The difference between the pre-crisis and the Bai-Perron subsamples in the events included as notifications of additional information is that the former has two extra announcements due to its greater length. These are the additions made by the Romanian and Danish governments to their originally submitted plans. The fact that after their removal from the carbon time series the event category gains statistical significance suggests that these two announcements did not produce any event returns and washed away the event returns associated with the remainder of the notifications.

The rest of the findings are identical to the pre-crisis ones - announcements about the expansion of the EU ETS lead to significant increases in EUA prices, the disclosure of verified emissions for 2005 is associated with positive event returns, and lastly, the inability of COP/MOP participants to agree on a legally binding, international post-2012 climate policy is reflected in the negative event returns following the 2006 annual meeting in Kenya.

B. Subsample 2 (27/12/2006 – 21/06/2007)

The short time period which this subsample covers (125 trading days) raises issues about the reliability of the test statistics. Despite the poor fit of the regression (adjusted R-squared is negative for both sets of regression equations at -0.49% for the intraphase EUA futures and -2.13% for the interphase ones) I briefly mention the price effects of announcements within this time period. The Bulgarian council's approval of the Phase II NAP ("Leaked information prior to formal submission to the EC") does not have a statistically significant impact on the carbon price over the period. Notifications of additional information to original proposals seem to have a contradictory impact on the prices of nearest-to-maturity and near phase EUA futures contracts. At the same time additions to an already revised plan (in this subsample, the announcement refers to the Lithuanian revised plan) are associated with negative event returns in both futures price series. All in all, the market does not seem to view the suggested additions as enough to prop up the carbon price. The lack of commitment in member states covered by the ETS, as reflected in the insufficient proposed changes, appears to be undermining not only the short-term prices but also the long-term prospects of the market. Lastly, the formal acceptance of a second Phase NAP by the EC is shown to be the only event associated with a statistically significant positive price effect.

C. Subsample 3 (22/06/2007 – 30/06/2011)

Because this subsample almost perfectly overlaps with the full-crisis sample period analysed in Part B of Section 3.6.1.1 (the latter is less than two months shorter), the results in the last four columns of Table 3.7 are nearly identical to the ones presented in

Table 3.7 Univariate analysis: Bai-Perron structural breaks

This table reports the regression results of Equation 1. The sample is split into three subsamples - (22/04/2005 - 26/12/2006), (27/12/2006 - 21/06/2007) and (22/06/2007 - 30/06/2011) according to the Bai-Perron algorithm. The dependent variable is: 1) log-return of nearest-to-expiry EUA futures contracts, 2) near-phase EUA futures. Robust Newey-West HAC standard errors are used. The corresponding t-statistics are reported in parentheses. Event return is denoted as R_e and non-event return – as R_{ne}.

Event	Subsample 1				Subsample 2				Subsample 3			
	Intraphase R_e		Interphase R_e		Intraphase R_e		Interphase R_e		Intraphase R_e		Interphase R_e	
Intercept (R_{ne})	-0.0032	(-1.57)	-0.0003	(-0.18)	-0.0312*	(-3.71)	0.0014	(0.48)	-0.0013	(-1)	-0.0005	(-0.73)
NAP I: Additional info	0.0346*	(10.6)	0.0314*†	(10.48)								
NAP I: Acceptance	0.0715*	(35.31)	0.0674*†	(42.7)								
NAP I: Rejection	0.0013	(0.67)	-0.0183*†	(-11.6)								
NAP II: Leaked info	-0.0257**	(-2.03)	-0.0184	(-1.57)	-0.0063	(-0.75)	-0.0020	(-0.68)	0.0161*	(12.34)	0.0140*	(19.93)
NAP II: Notification to EC	-0.0065	(-1.08)	-0.0037	(-1.62)					-0.0292*	(-22.38)	-0.0301*	(-43.01)
NAP II: Additional info	-0.0177*	(-8.79)	-0.0092*	(-5.83)	-0.0260*	(-3.1)	0.0136*	(4.76)	0.0384	(1.45)	-0.0101	(-0.87)
NAP II: Amended plan									0.0103*	(3.14)	0.0066*	(3.62)
NAP II: Additional info to amended plan					-0.1630*	(-19.42)	-0.0184*	(-6.43)	0.0966*	(74.01)	-0.0097*	(-13.91)
NAP II: Acceptance					0.0312*	(3.71)	0.0287*	(10.05)	-0.0253	(-1.47)	-0.0017	(-0.47)
EC announcement after its formal decision									-0.0141	(-1.24)	-0.0142	(-1.6)
Phase III: Caps									0.0142	(1.6)	0.0120	(1.54)
Phase III: Auctioning rules									0.0182*	(2.66)	0.0154*	(2.72)
Scope	0.0348*	(3.1)	0.0155**	(2.35)					0.0014	(0.12)	-0.0079	(-1.43)
Verification 2005	0.4879*	(242.2)	0.1868*	(118.3)								
Verification 2007									0.0405*	(31.02)	0.0397*	(56.65)
Verification 2008									0.0405*	(31.05)	0.0241*	(34.44)
Verification 2009									0.0214*	(16.37)	0.0183*	(26.09)
Other: UK									-0.0035	(-0.34)	0.0007	(0.1)
Other: Germany									0.0193*	(14.82)	0.0171*	(24.43)
CITL – ITL linkage									0.0151	(1.61)	0.0169**	(2.09)
CERs									0.0044	(1.43)	0.0010	(0.36)
COP/MOP	-0.0155*	(-7.7)	-0.0128*	(-8.1)					-0.0008	(-0.28)	-0.0013	(-0.51)
R-squared	27.51%		9.88%		2.75%		1.16%		1.57%		1.83%	
Adjusted R-squared	25.95%		7.94%		-0.49%		-2.13%		-0.17%		0.09%	

*, **, *** refer to significance at the 1%, 5% and 10% level respectively

† indicates that although a price is quoted on the ECX, trading in these futures hasn't started yet

Table 3.5. It is worth noting that partitioning the dataset into subsamples according to the Bai-Perron algorithm seems to be somewhat better in terms of overall model performance than dividing the data into pre-crisis and full-crisis subsamples. To illustrate, the adjusted R-squared of the pre-crisis subsample is 10.29% (5.89%) for intra-(inter) phase futures and it goes up to 27.51% (9.88%) for the Bai-Perron Subsample 1. A change in the adjusted R-squared from -0.94% (0.14%) for the full-crisis sample to -0.17% (0.09%) for the Bai-Perron Subsample 3 is observed. While the coefficients of determination are not directly comparable due to the different lengths of the periods, they point to differences in performance.

3.6.2. MULTIVARIATE CARBON PRICE ANALYSIS

Explanatory variables used in OLS-based studies of the carbon market vary across researchers. The motivation behind the choice of variables for Equation 2 has already been discussed in Section 3.4.1.2 and the descriptive statistics are summarized in Table 3.8 below. With largest standard deviations and maximum-minimum ranges, gas and intraphase EUA futures appear to be the most volatile. None of the variables is normally distributed.

In Section 3.4.1.2 it was also discussed that, in order to prevent endogeneity problems with the regression analysis, I have chosen regressors which are not highly correlated. Table 3.9 presents the correlation matrices in price levels and log-returns. The correlations between log-returns (Panel B) are much lower than the correlations between prices (Panel A). None of the correlations are so high as to suggest that multicollinearity or endogeneity biases are introduced in the model.

Table 3.8 Descriptive statistics

This table reports the descriptive statistics of the log-returns for the ICE Natural Gas 1 Month forward contracts, the near-month ICE Brent Crude Oil futures contracts, DJ EuroStoxx600, intra- and interphase ECX EUA futures contracts over the period 22/04/2005 - 30/06/2011.

	Gas	Oil	Equity	Intraphase EUAs	Interphase EUAs
Mean	0.00	0.00	0.00	0.00	0.00
Maximum	0.48	0.14	0.10	0.48	0.19
Minimum	-0.26	-0.12	-0.08	-0.45	-0.29
Std. Dev.	0.05	0.02	0.01	0.05	0.03
Skewness	2.61	-0.1	-0.01	-0.19	-0.9
Kurtosis	22.64	6.47	10.15	28.90	18.06
Jarque-Bera	26971.60	789.37	3391.29	44436.95	15249.67
Observations	1568	1568	1594	1589	1590

Table 3.9 Correlation analysis

This table represents a cross-correlation analysis in price levels (Panel A) and in log returns (Panel B). The dataset covers the period 22/04/2005 – 30/06/2011.

Panel A: Correlation matrix in price terms

	Gas	Oil	Equity	Intraphase EUAs	Interphase EUAs
Gas	1.00	0.33	0.11	0.54	0.46
Oil		1.00	0.14	0.32	0.43
Equity			1.00	-0.31	0.29
Intraphase EUAs				1.00	0.56
Interphase EUAs					1.00

Panel B: Correlation matrix in log returns

	Gas	Oil	Equity	Intraphase EUAs	Interphase EUAs
Gas	1.00	0.09	0.06	0.13	0.14
Oil		1.00	0.32	0.13	0.20
Equity			1.00	0.10	0.15
Intraphase EUAs				1.00	0.55
Interphase EUAs					1.00

3.6.2.1. The financial crisis and its impact on the carbon price dynamics

A. Pre-crisis multivariate model

The results of Equation 2 for both the pre-crisis and full-crisis subsamples are reported in Table 3.10. Looking at the pre-crisis time period first, it appears that changes in energy prices, stock prices and extreme weather explain a considerable portion of the variability in carbon prices. Adjusted R-squared for the intraphase (interphase) EUA futures regression increases from 10.29% (5.89%) to 13.06% (8.50%) compared to the univariate regressions. The model performance is in line Mansanet-Bataller and Pardo (2009) who, modelling carbon returns as a function of oil, gas and coal, report adjusted R-squared of 17.78% for intraphase futures over a period nearly overlapping with the pre-crisis subsample (25/10/2004 – 15/05/2007).

Before the start of the crisis, carbon is found to trade on its fundamentals – the energy complex and extreme weather. Oil appears to be the most important driver of carbon prices. The regression coefficients of oil are numerically much larger than the ones for gas: 0.41(0.23) for intraphase (interphase) EUA futures relative to 0.13 (0.06) for gas. The relationship between the two energy variables and carbon is such that oil and gas price increases are associated with increases in EUA prices. Equity and carbon prices do not seem to be related, as demonstrated by the insignificant slope coefficients of the DJ EuroStoxx index. This finding is in line with Bonacina et al. (2009) who argue that before the financial crisis carbon allowances behaved like commodities rather than financial assets. A non-linear relationship between weather and the price of carbon is documented whereby extremely hot and cold days lead to positive abnormal returns

(β_{hot}= 0.0125, β_{cold}= 0.0143). Naturally, the significance of extreme temperatures is only limited to the near expiry contracts.

Similar to the results from the univariate pre-crisis analysis in Part A of Section 3.6.1.1, notifications of additional information to trial period NAPs and the plans' acceptances or rejections by the EC are associated with positive event returns for Phase I futures contracts. As already discussed, Phase II futures were not traded at the time when NAP I announcements were made and the regression coefficients for these events do not reflect investors' beliefs. Leaked information prior to the formal submission of Phase II NAPs leads to statistically significant price declines in the intraphase EUA futures, suggesting that market participants consider the proposed emissions targets to be insufficient to sustain the carbon price. The observed reaction is, however, inconsistent with the ban on allowance transferability between the first two phases.

Notifications to the EC and additional information to the originally proposed Phase II NAPs seem to have no meaningful impact on the price development of EUA futures contracts. However, notifications of additional information to amended plans have a significant negative impact on the prices of Phase II EUA futures. The formal acceptance of NAPs II by the EC does not affect the prices of inter- or intraphase EUA futures contracts as, following all the amendments and corrections, all necessary information is already incorporated in the prices of carbon instruments.

Contrary to Hypothesis 2, news about the expansion of the EU ETS have led to positive event returns in the price series of Phase I futures only and have had no statistically significant impact on the Phase II EUA futures prices. The announcements themselves

Table 3.10 Multivariate analysis: before and during the financial crisis

The table reports the regression results of Equation 1. The sample is split into pre-crisis (22/04/2005 - 16/08/2007) and full-crisis (17/08/2007 - 30/06/2011) subsamples. The dependent variable is: 1) log-return of nearest-to-expiry EUA futures contracts, 2) near-phase EUA futures. Robust Newey-West HAC standard errors are used. The corresponding t-statistics are reported in parentheses. Event return is denoted as R_e and non-event return – as R_{ne}.

Event	Pre-crisis subsample				Full-crisis subsample			
	Intraphase R_e		Interphase R_e		Intraphase R_e		Interphase R_e	
Intercept (R_{ne})	-0.0100*	(-3.84)	-0.0004	(-0.27)	-0.0012	(-0.88)	-0.0005	(-0.71)
Oil	0.4123*	(3.13)	0.2331*	(3.54)	0.1658*	(3.66)	0.1570*	(5.09)
Gas	0.1307*	(3.8)	0.0644*	(3.67)	0.1114*	(2.68)	0.0752*	(3.53)
Equity	-0.1809	(-0.55)	-0.0368	(-0.25)	0.3067*	(4.66)	0.2060*	(4.39)
Cold	0.0143*	(2.39)	0.0067	(0.92)	-0.0114***	(-1.97)	-0.0113**	(-2.32)
Hot	0.0125*	(2.63)	0.0023	(0.56)	0.0031	(0.62)	0.0052	(1.03)
NAP I: Notification of additional information	0.0483*	(10.7)	0.0353* †	(18.28)				
NAP I: Acceptance	0.0646*	(13.5)	0.0647* †	(15.97)				
NAP I: Rejection	0.0200*	(4.05)	-0.0124* †	(-5.24)				
NAP II: Leaked info before formal submission	-0.0231**	(-2.02)	-0.0169	(-1.56)	0.0156*	(11.22)	0.0129*	(12.88)
NAP II: Notification to the EC	0.0063	(1)	-0.0003	(-0.14)	0.0045	(0.86)	-0.0048	(-1.55)
NAP II: Notification of additional information	0.0022	(0.08)	-0.0102	(-0.8)	-0.0027	(-1.31)	0.0031**	(2.5)
NAP II: Notification of amended plan					0.0084*	(3.79)	0.0054*	(4.85)
NAP II: Additional information to amended plan	-0.0419	(-0.42)	-0.0142*	(-6.95)				
NAP II: Acceptance	-0.0222	(-1.35)	0.0022	(0.22)	-0.0207	(-0.78)	0.0002	(0.05)
EC announcement after its formal decision					-0.0113	(-1.56)	-0.0114**	(-2.04)
Phase III: Emissions caps					0.0114***	(1.83)	0.0094***	(1.68)
Phase III: Auctioning rules					0.0185*	(3.05)	0.0148*	(2.83)
Scope	0.0367*	(4.14)	0.0131	(1.66)	0.0042	(0.36)	-0.0060	(-1.2)
Verification 2005	0.4956*	(76.58)	0.1887*	(65.69)				
Verification 2007					0.0291*	(14.31)	0.0304*	(23.88)
Verification 2008					0.0309*	(8.62)	0.0183*	(10.19)
Verification 2009					0.0148*	(8.84)	0.0132*	(13.02)
Other announcements: UK					0.0034	(0.78)	0.0064***	(1.69)
Other announcements: Germany					0.0142*	(6.21)	0.0136*	(12.46)
CITL – ITL linkage					-0.0062	(-0.25)	0.0027	(0.15)
CERs					0.0031	(0.85)	-0.0005	(-0.18)
COP/MOP	-0.0011	(-0.24)	-0.0082*	(-3.48)	0.0041	(0.65)	0.0024	(0.45)
R-squared	15.44%		11.01%		6.38%		12.70%	
Adjusted R-squared	13.06%		8.50%		4.23%		10.70%	

*, **, *** refer to significance at the 1%, 5% and 10% level respectively

† indicates that although a price is quoted on the ECX, trading in these futures hasn't started yet

include the presentation of the EC's plan to include aviation; the EU environment ministers' announcements of support for the plans to include aviation in the ETS; the signing of climate co-operation agreement between the UK Prime Minister Tony Blair and California Governor Arnold Schwarzenegger whereby California committed to investigating the possibility of linking to the ETS. As these announcements relate to proposed changes for Phase II and III, the observed event reaction in Phase I futures is inconsistent with the ban on allowances banking between the first and second trading periods.

Similar to the results from Section 3.6.1.1, the COP/MOP event negatively surprises market participants (statistically significant regression coefficient of -0.008 for Phase II EUA futures contracts). Once again, a positive impact is found of the disclosure of 2005 verified emissions data on the prices of both Phase I and II EUA futures contracts. A detailed explanation of the seemingly contradictory positive price effect following the information release of May 15th 2006 was offered in Part A of Section 3.6.1.1.

B. Full-crisis multivariate model

The results of Equation 2 for the full-crisis subsample are reported in the last four columns of Table 3.10. A meaningful improvement in the performance of the multifactor full-crisis regressions over the univariate analysis (Table 3.5) is reported. After the inclusion of oil, gas, equity and extreme weather as explanatory variables adjusted R-squared increases from -0.94% (0.14%) to 4.23% (10.70%) for the intra- (inter) phase EUA futures regression. Oil and gas remain statistically significant at the 1% level for both carbon price series. During the crisis, the association between equity and carbon prices also gains statistical significance. The slope coefficient of the DJ EuroStoxx index is even greater numerically than the coefficients of oil and gas, implying that changes in the expected level of economic activity explain a larger part of the carbon price variation than the energy price drivers. Bonacina et al. (2009) similarly demonstrate that in the aftermath of the crisis, carbon prices have become more strongly correlated with the prices of equity, as proxied by the DJ Euro STOXX 50. Declercq et al. (2011) confirm that carbon behaves like a financial asset after the crisis. The explanation given for this phenomenon is that in times of tight credit conditions and cash deficiencies in the balance sheets of many firms, regulated entities choose to monetize their allowances rather than bank them for a future period (Bonacina et al., 2009). As for the role of weather in explaining carbon returns variation, extremely hot days are found to be statistically insignificant. Extremely cold days, on the other hand, are associated with a significantly negative return. This contradicts the economic logic that unusually cold weather increases demand for energy and thus indirectly leads to carbon price jumps. The results, however, are not significant at the preferred 99% confidence interval.

Looking at NAP II announcements, leaked information has a positive and significant impact on both intra- and interphase carbon prices (0.0156 and 0.0129, respectively). The event relates to the leaked information about Estonia's national cap revision. The rumour that it would submit a downwardly revised emissions plan and drop the threats of further court hearings in an attempt to end the long dispute over its allocation plan was greeted by market participants as good news. The notion that EU member states which are unhappy with their allocations can, at will, sue the EC and challenge its authority in regulating the ETS undermines confidence in the market altogether. Estonia dropping the case and revising its cap down to 14.3mt per year of CO_2 emissions seem to have strengthened a little the shaky confidence in the cap-and-trade scheme.

While notifications of Phase II NAPs create no event returns in the EUA futures, notifications of additional information to the already submitted plans positively affect interphase futures. Similarly, the submission of amended plans and downward revisions in the proposed emissions caps for Estonia and Bulgaria have a significant positive impact on both carbon price series. Since there is bankability between Phase II and III of the ETS, both nearest-to-expiry and interphase futures are affected alike by these events. In line with the results elsewhere, the actual acceptance of the Phase II NAPs creates no event returns.

Developments in the NAP process after the EC formal decisions have a negative impact on the interphase EUA price dynamics. The results refer to Estonia's attempt to get 2.3 million extra EUAs, Latvia's claim for more Phase II EUAs and Italy's attempt to renegotiate its emissions cap. It is only natural that claims of individual member states after the EC final decision would create uncertainty in the market and exert downward pressure on carbon prices.

As hypothesized, news about the tightening of the post-2012 emissions caps and the increasing portion of EUAs being auctioned rather given for free are good news for the market and are associated with positive event returns for both the intra- and interphase EUA futures contracts. At the same time, announcements about the scope of the EU ETS don't seem to meaningfully affect carbon prices. Before the crisis, the scope-related announcements had a modest but statistically significant positive event return on the price of EUA futures. In terms of the annual verification events, as in Table 3.5, positive price effects are found for the 2007, 2008 and 2009 data releases.

The events categorized as "Other announcements: UK" are found to lead to positive event returns for interphase EUA futures contracts. The announcements included the proposed strengthening of the British Climate Change Bill; the commitment to an 80% cut in greenhouse gas emissions from 1990 levels by 2050, up from the previous goal of a 60% reduction; the goal to reduce emissions by 34% from 1990 levels by 2020, and 50% below 1990 levels by 2025; the refusal to bank emission savings from Phase II on to Phase III. These are all viewed by the market participants as good news for the carbon market, as evidenced by the significant slope coefficient. Similarly, the announcement by Germany that the country will aim to cut its emissions by 55% by 2030 and by 70% by 2040 creates statistically significant positive event returns in both EUA price series which I examine (regression coefficients for "Other announcements: Germany" are 0.0142 and 0.0136 for the intra- and interphase EUA futures, respectively) . These results confirm the view that due to the size of EUAs allocated to them, the UK and Germany affect the carbon price dynamics via the climate policies they adopt.

After the onset of the crisis, announcements related to the linkage of the EU ETS to the Kyoto Protocol Clean Development Mechanism, and news about the quantities and types of CERs which can be used for compliance purposes don't seem to play a role in the carbon price dynamics. The reason might be that during the financial crisis and the following periods of global recession, firms realize they will be net long allowances and underreact to news about the possibility of using alternative carbon offsets for compliance. Similar reasoning can be offered about the insignificance of the COP/MOP events. With the low expectations of participants, when no consensus is reached there are no surprises.

All in all, the majority of the event returns found with the univariate analysis in Section 3.6.1.1 are robust to the addition of energy prices, economic activity and extreme weather to the model.

3.6.2.2. The multifactor model with structural breaks

In this portion of the analysis, the Bai-Perron test is re-estimated for the multivariate carbon price analysis. The dataset is divided at such times where the underlying relationship between carbon, gas, oil, equity and extreme weather changes. The results of the Bai-Perron test with a minimum of 44 trading days per segment are reported in Table 3.11 below. The BIC is minimized for two breaks and the RSS shows little improvement after the second break. The two points of structural change correspond to the following dates: December 18th, 2006 and April 5th, 2007. The three subsamples are therefore: 22/04/2005 – 17/12/2006; 18/12/2006 – 04/04/2007 and 05/04/2007 – 30/06/2011. Again, the identified subsamples relate closely to the pre-crisis/ full-crisis division used earlier.

Table 3.11 Bai-Perron RSS and BIC output (Multivariate analysis)

Number of breaks	0	1	2	3	4	5
RSS	3.54	3.49	3.36	3.30	3.22	3.19
BIC	-5054.87	-5040.97	-5061.14	-5055.58	-5055.39	-5032.52

*RSS = Residual Sum of Squares; BIC = Bayesian Information Criterion
**BIC is minimized for two breaks and RSS shows little improvement after the second break.

A. Subsample 1 (22/04/2005 – 17/12/2006)

The results of Equation 2 for all three Bai-Perron subsamples are reported in Table 3.12. In Subsample 1, oil and natural gas are found to be important drivers of carbon while the relationship between equity and carbon is insignificant. Extremely hot and cold days elicit strong market reactions, confirming the view that higher demand for energy during days of extreme weather affects the price dynamics of carbon. For brevity, I only mention the results where they differ from the ones of the pre-crisis subsample reported in Part A of Section 3.6.2.1.

Leaked information prior to formal submission of plans to the EC has led to statistically significant price declines for both intra- and interphase futures prices. This suggests that the information released to the public raised doubt about the sustainability of the carbon price. Submission of Phase II plans to the EC is not associated with significant event returns. Unlike the pre-crisis sample (see Table 3.10) where no event returns are reported, in this subsample the notification of additional information to an already submitted NAP II has led to negative event returns for both intra-and interphase EUA futures contracts. (-0.0186 for Phase I futures and -0.0108 for Phase II futures). The notification examined in this subsample is the one made by France in October 2006 while two additional notifications are covered by the longer pre-crisis sample – the one by Romania in April 2007 and by Denmark in July 2007. The rest of the findings are identical to the results presented in Table 3.10.

B. Subsample 2 (18/12/2006 – 04/04/2007)

This subsample covers the period before the onset of the financial crisis. The extreme weather variables are removed from the regression because over the period, there are no observations characterized by extreme temperatures. Oil and gas enter the regression with statistically significant and positive slope coefficients as suggested by economic theory. The DJ EuroStoxx index has no meaningful association with the carbon price. The two events covered in this fairly short subsample refer to the leaked information that Bulgaria's council of ministers approved a draft national allocation plan for the second phase of the EU ETS and also the Romanian notification of additional information to their already submitted NAP II. The former has a negative impact on the Phase I futures, which is inconsistent with ban of allowance transferability, while the latter has a positive impact on the Phase II futures.

C. Subsample 3 (05/04/2007 – 30/06/2011)

This subsample starts 3 months before the crisis and covers the full-crisis period. The regression results are presented in the last four columns of Table 3.12. With regression coefficients of 0.1615 and 0.161 for intra- and interphase futures, oil is found to be among the most important factors driving carbon prices. Similar to the results in Table 3.10, equity and carbon prices exhibit a significant positive relationship after the onset of the financial crisis. Gas is also found to be statistically significant for both nearest-to-maturity and near phase EUA contracts. Contrary to economic logic, however, its sign is negative even though it has been consistently positive in the periods leading up to the financial crisis. The significant negative regression coefficient of extremely cold weather is also counterintuitive. These results seem to suggest that there is no stable relationship between the market and its fundamentals.

Table 3.12 Multivariate analysis: Bai-Perron structural breaks

This table reports the regression results of Equation 1. The sample is split into three subsamples - (22/04/2005 - 17/12/2006), (18/12/2006 - 04/04/2007) and (05/04/2007 - 30/06/2011) according to the Bai-Perron algorithm. The dependent variable is: 1) log-return of nearest-to-expiry EUA futures contracts, 2) near-phase EUA futures. Robust Newey-West HAC standard errors are used. The corresponding t-statistics are reported in parentheses. Event return is denoted as R_e and non-event return – as R_{ne}.

Event	Subsample 1				Subsample 2				Subsample 3			
	Intraphase R_e		Interphase R_e		Intraphase R_e		Interphase R_e		Intraphase R_e		Interphase R_e	
Intercept (R_{ne})	-0.0042	(-1.8)	-0.0008	(-0.46)	-0.0208**	(-2.03)	0.0013	(0.35)	-0.0031**	(-2.16)	-0.0002	(-0.34)
Oil	0.3638*	(3.4)	0.2447*	(3.13)	1.0817***	(1.98)	0.1289	(0.7)	0.1615*	(3.35)	0.1610*	(5.27)
Gas	0.0713*	(3.55)	0.0405**	(2.3)	0.6641*	(3.25)	0.3127*	(3.39)	-0.0166*	(-4.17)	-0.0140*	(-4.57)
Equity	0.1762	(0.46)	-0.2729***	(-1.35)	-1.3246	(-1.63)	0.3334	(1.1)	0.1658**	(2.15)	0.1169***	(2.1)
Cold	0.0088**	(1.88)	0.0067	(0.86)					-0.0069	(-1.23)	-0.0097***	(-2.08)
Hot	0.0087**	(2.05)	0.0054	(1.46)					0.0026	(0.49)	0.0029	(0.53)
NAP I: Additional info	0.0411*	(11.04)	0.0363*†	(15.49)								
NAP I: Acceptance	0.0636*	(13.3)	0.0603*†	(16.27)								
NAP I: Rejection	0.0086**	(2.27)	-0.0103*†	(-3.53)								
NAP II: Leaked info	-0.0258***	(-1.93)	-0.0205***	(-1.7)	-0.0272*	(-2.84)	-0.0051	(-1.37)	0.0149*	(9.8)	0.0107*	(12.43)
NAP II: Notification to EC	-0.0004	(-0.07)	-0.0001	(-0.03)					-0.0127*	(-3.69)	-0.0176*	(-6.94)
NAP II: Additional info	-0.0186*	(-6.58)	-0.0108*	(-5.8)	-0.0081	(-0.55)	0.0275*	(5.07)	0.0378	(1.32)	-0.0124	(-1.23)
NAP II: Amended plan									0.0094*	(3.56)	0.0042*	(3.32)
NAP II: Additional Info to amended plan									-0.0456	(-0.44)	-0.0131*	(-5.28)
NAP II: Acceptance									-0.0198	(-1.27)	0.0024	(0.45)
After EC formal decision									-0.0095	(-1.14)	-0.0116**	(-1.9)
Phase III: Emissions caps									0.0137**	(2.24)	0.0095***	(1.73)
Phase III: Auctioning rules									0.0183*	(2.71)	0.0133**	(2.39)
Scope	0.0331*	(3.81)	0.0131	(1.59)					0.0062	(0.52)	-0.0060	(-1.16)
Verification 2005	0.4961*	(64.65)	0.1870*	(47.45)								
Verification 2007									0.0349*	(17.05)	0.0325*	(25.06)
Verification 2008									0.0431*	(20.52)	0.0251*	(24.33)
Verification 2009									0.0178*	(9.09)	0.0134*	(11.76)
Other: UK									0.0036	(0.45)	0.0051	(0.9)
Other: Germany									0.0214*	(15.2)	0.0170*	(24.22)
CITL – ITL linkage									0.0189*	(2.55)	0.0185*	(2.85)
CERs									0.0042	(1.46)	-0.0015	(-0.58)
COP/MOP	-0.0065	(-1.45)	-0.0073**	(-2.53)					0.0030	(0.68)	0.0001	(0.02)
R-squared	31.76%		12.88%		19.02%		23.82%		3.00%		8.13%	
Adjusted R-squared	29.40%		9.86%		13.06%		18.22%		0.87%		6.12%	

*, **, *** refer to significance at the 1%, 5% and 10% level respectively

† indicates that although a price is quoted on the ECX, trading in these futures hasn't started yet

Such inconsistent responses to key price drivers like fuel prices and weather have been documented elsewhere in the carbon literature and interpreted as market inefficiency (Hintermann, 2010). The idea that price drivers change in response to the changing institutional context of the EU ETS has also been advanced in several studies (among others Alberola et al., 2008). Keppler and Mansanet-Bataller (2010) and Koop and Tole (2011) demonstrate that the differing context of the individual trading periods alters the causal links between electricity, carbon and gas prices and factors such as weather or equity valuations.

As for the event returns associated with the various types of announcements, they are almost identical to the results reported in Table 3.10 so no further discussion of the results is needed. Similar to the univariate carbon price analysis from Section 3.6.1, I report that partitioning the dataset into subsamples according to the Bai-Perron algorithm produces somewhat better results than dividing the data into pre-crisis and full-crisis subsamples. To illustrate, the adjusted R-squared of the pre-crisis subsample is 13.06% (8.50%) for intra-(inter) phase futures and it goes up to 31.76% (12.88%) for the Bai-Perron Subsample 1 and to 19.02% (23.82%) for Subsample 2. A decline in the adjusted R-squared from 4.23% (10.70%) for the full-crisis subsample to 0.87% (6.12%) for the Bai-Perron Subsample 3 is observed. Due to the different structural breaks identified by the Bai-Perron method in the univariate and multivariate analysis, a direct comparison of the subsamples is not possible. It is worth noting, however, that OLS regressions in the multivariate Bai-Perron framework produce a much higher coefficient of determination compared to the univariate ones.

In terms of changes in the market sensitivity to announcements before and during the crisis, I confirm that the market has become less responsive following the start of the financial crisis. A quick look at Subsample 1, which is before the onset of the crisis, and Subsample 3, which covers the period of the crisis, shows a reduction in the coefficient of variation – from 29.40% (9.86%) for the intra-(inter) phase EUA futures in Subsample 1 to 0.87% (6.12%) for the futures in Subsample 3. The decline in adjusted R-squared demonstrates that announcements about the institutional framework of the EU ETS explain substantially less of the variance in carbon returns after the onset of the financial crisis.

A caveat to the analysis concerns the role played by expectations in the development of the hypotheses and the estimation of returns associated with institutional announcements. As mentioned in Section 3.3, estimates are conditioned on the assumption that all announcements identified in this chapter represent genuine news to the market. Because of their unscheduled nature, the announcements are highly unpredictable (at least with regards to timing). Nevertheless, the developments and announcements in the market mostly take place as a structured process. For instance, as pointed out in Section 3.2.1.1, getting a NAP approved is a process which involves multiple steps known in advance – draft proposals, submission to the EC, negotiations between the national government and the EC, followed by the formal EC decision. While the exact timing of each step of this process may not be anticipated by the market, it is plausible that some expectations about the end decisions (i.e. allocations to individual member states) are already embedded in the price of carbon.

This implies that many of the announcements examined in this chapter may not constitute a genuine shock to the market. Intermediate announcements (i.e. additions to submitted plans, amended plans, etc.) can therefore be interpreted as mostly noise which reveals little incremental information after the original submissions of the plans – which would explain the very small coefficients associated with most announcements in the OLS regressions. By the same token, news about MPs support of aviation's inclusion in the EU ETS, Senate approval of the same, and similar announcements are mostly noise, as the signal (an expanding EU ETS) is already expected by the market, albeit with an uncertain timing. This might explain why, for most of the events analyzed in this chapter, the event returns are fairly small in magnitude (mostly around 1% and in a few cases up to 2%, with only the verification events producing more substantial price reactions).

3.6.3. THE IMPACT OF ANNOUNCEMENTS ON VOLATILITY

This section reports the findings on the impact of institutional announcements on the volatility of carbon returns. The results of the Brown-Forsythe and sign tests are presented in Table 3.13 below. Panel A and B document the influence of announcements on the variance of intraphase and interphase carbon futures prices, respectively. Focusing on the Brown-Forsythe (1974) test for intraphase EUA futures contracts, the null hypothesis of variance homogeneity is never rejected for the majority of event categories at the 5% significance level. Only for two sub-categories of NAP II events (notifications of additional information and notifications of additional information to amended plans) do I find that the null hypothesis is rejected in 25% and 50% of the time, respectively. The former are shown to lead to a lower variance after the announcements and the latter to a higher variance. With regards to the impact of announcements on the volatility of interphase carbon returns, the null hypothesis is rejected 25% of the time following a Notification of a Phase II NAP to the EC. The one-tailed test demonstrates that Acceptances of Phase II NAPs also lead to a variance increase in 14.29% of all cases in that sub-category. For the rest of the announcements, there is no statistically significant change in the variance of returns.

The results from the sign test unanimously suggest that the volatility of carbon returns has remained unchanged following the announcements release for both intra- and interphase futures contracts. The p-values for all two-tailed and one-tailed tests are greater than the 5% significance level at which the test has been performed. Therefore, the null hypothesis of equal volatility before and after announcements is not rejected.

I proceed to examine the influence of the announcements on the volatility embedded in carbon options. To formally test whether the observed changes in implied volatility are statistically significant, I estimate Equation 3 and report the results in Table 3.14. The results in Panel A are aggregated across broad event categories while Panel B reports the results for each sub-category of events. Save for the annual compliance events and the COP/MOP meetings, all analysed events are unscheduled. Looking at the aggregates first (Panel A), implied volatility on any given day does not seem to differ significantly from the average implied volatility over the 10-day period around unscheduled events. Announcements related to the EU ETS scope are the only exception, where significant deviations from the averages are found for days -5,-4 and +1. The dummy coefficients reveal declines in volatility prior to the event and an increase after the event. Albeit insignificant, the remainder of the dummy variables suggest a rise in volatility after an announcement related to the expansion of the ETS is made.

For verification events, implied volatility is not significantly different from its mean for days -2 to +1. Implied volatility before day -2 is significantly higher than the observed average, and volatility after day +1 is statistically significantly lower as uncertainty is removed from the market following data publication. These findings are consistent with those of Chevallier et al. (2008) who also document a reduction of volatility following the release of the 2006 verified emissions data. Implied volatility changes in a similar fashion around COP/MOP meetings but the size of the coefficients is substantially smaller, implying that changes in volatility are much smaller relative to changes around the annual verification events. This result may be due to the fact that United Nation's meetings last much longer and information may be gradually incorporated in the prices, precluding dramatic changes in volatility. The conclusions are qualitatively identical when sub-categories of events are analysed (Panel B of Table 3.14) rather than the general classification discussed so far.

In brief, both the Brown-Forsythe and the sign tests demonstrate that announcements related to the institutional set-up of the scheme have an insignificant impact on the variance of carbon returns. This result is in line with earlier studies (Mansanet-Bataller and Pardo, 2009; Lepone et al., 2011) which find that NAP events and annual disclosures of verified emissions have no impact on carbon volatility. Additionally, I demonstrate that announcements about Phase III caps, CER availability, CITL-ITL linkage, ETS scope, and COP/MOP meetings do not impact the variance of carbon returns either. Lepone et al. (2011) attribute the lack of a change in variance of returns to information leakage prior to public releases. They argue that "a select group of employees and firm level auditors are apt to information regarding caps […] increasing the likelihood of information leakage and insider trading" (Lepone et al., 2011: p.71). While I do not aim to disprove earlier research, I am suspicious of claims about such en masse insider trading particularly before unscheduled events.

I propose one possible explanation that on the event days market participants revise their assessment of EUA prices but that this re-assessment may not be large enough to induce statistically significant changes in volatility. Alternatively, the reported lack of changes in volatility before and after institutional announcements is also consistent with the notion that much of the information flooding the market (and therefore, many of the announcements examined in this chapter) constitutes noise and not news. In short, news would seem to be no news at all, under this explanation. It would appear that the critical price driver and major source of news for the market is the annual verification events. The verification process is central to the development of the carbon market because it simultaneously reveals the remaining supply of emissions allowances and, therefore, the potential future demand for these. These are associated with statistically significant event returns, and these are the largest in magnitude of all the examined announcements, and they also lead to meaningful changes in option implied volatility, which suggests that these events alter the participants' perception of the market risk.

To sum up, with the Brown-Forsythe and sign tests I confirm earlier findings in the literature that the announcements have no impact on the variability of carbon returns. By using option implied volatility though, I demonstrate that following verification events and COP/MOP meetings the implied volatility embedded in carbon option decreases. This suggests a lower overall level of uncertainty in the market and confirms the importance of these events for market players.

Table 3.13 Changes in the variance of carbon returns

This table reports the results of a Brown-Forsythe (1974) robustness test for equality of variances and a sign test. The null hypothesis is that the variance during the 5 days preceding the announcement day is equal to the variance in the period comprised of the event day and the following 4 days. Three alternative hypothesis specifications are testes: $\boldsymbol{\sigma}_{\mathbf{before}} \neq \boldsymbol{\sigma}_{\mathbf{after}}$,$\boldsymbol{\sigma}_{\mathbf{before}} > \boldsymbol{\sigma}_{\mathbf{after}}$ and $\boldsymbol{\sigma}_{\mathbf{before}} < \boldsymbol{\sigma}_{\mathbf{after}}$. For the Brown-Forsythe test, the number of times in which the null hypothesis is rejected is reported in percentage. For the sign test, the corresponding p-values are reported. Only events for which there are no confounding influences on the preceding or following day are used.

Panel A: Nearest-to-expiry futures contracts (Intraphase EUA futures)

	Number of events	**Brown-Forsythe test**			**Sign test**		
		$\sigma_0 \neq \sigma_1$	$\sigma_0 > \sigma_1$	$\sigma_0 < \sigma_1$	$\sigma_0 \neq \sigma_1$	$\sigma_0 > \sigma_1$	$\sigma_0 < \sigma_1$
NAP I: Acceptance by the EC	1	0%	0%	0%	1.000	0.500	1.000
NAP I: Rejection by the EC	1	0%	0%	0%	1.000	0.500	1.000
NAP II: Leaked information before formal submission to the EC	10	0%	0%	0%	0.754	0.828	0.377
NAP II: Notification of a plan to the EC	4	0%	0%	0%	0.625	0.938	0.313
NAP II: Additional information	4	25%	25%		0.625	0.938	0.313
NAP II: Amended plan	2	0%	0%	0%	1.000	0.750	0.750
NAP II: Additional information to amended plan	2	50%	0%	50%	1.000	0.750	0.750
NAP II: Acceptance by the EC	7	0%	0%	0%	1.000	0.656	0.656
NAP II: Announcements after the EC decision	3	0%	0%	0%	1.000	0.500	0.875
Phase III: Emissions caps	7	0%	0%	0%	1.000	0.500	0.773
Phase III: Auctioning rules	6	0%	0%	0%	1.000	0.656	0.656
Scope of the EU ETS	17	0%	0%	5.88%	0.629	0.315	0.834
Verification 2005	1	0%	0%	0%	1.000	0.500	1.000
Verification 2007	1	0%	0%	0%	1.000	0.500	1.000
Verification 2008	1	0%	0%	0%	1.000	1.000	0.500
Verification 2009	1	0%	0%	0%	1.000	1.000	0.500
Other announcements: UK	5	0%	0%	0%	0.375	0.969	0.188
Other announcements: Germany	1	0%	0%	0%	1.000	1.000	0.500
CITL-ITL linkage	2	0%	0%	0%	0.500	1.000	0.250
CERs	5	0%	0%	0%	1.000	0.813	0.500
COP/MOP meetings	4	0%	0%	0%	0.125	1.000	0.063

Panel B: Near phase futures contracts (Interphase EUA futures)

	Number of events	**Brown-Forsythe test** $\sigma_0 \neq \sigma_1$	$\sigma_0 > \sigma_1$	$\sigma_0 < \sigma_1$	**Sign test** $\sigma_0 \neq \sigma_1$	$\sigma_0 > \sigma_1$	$\sigma_0 < \sigma_1$
NAP I: Acceptance by the EC	1	0%	0%	0%	1.000	0.500	1.000
NAP I: Rejection by the EC	1	0%	0%	0%	1.000	0.500	1.000
NAP II: Leaked information before formal submission to the EC	10	0%	10%	0%	0.344	0.945	0.172
NAP II: Notification of a plan to the EC	4	25%	0%	25%	0.625	0.938	0.313
NAP II: Additional information	4	0%	0%	0%	0.125	1.000	0.063
NAP II: Amended plan	2	0%	0%	0%	0.500	1.000	0.250
NAP II: Additional information to amended plan	2	0%	0%	0%	1.000	0.750	0.750
NAP II: Acceptance by the EC	7	0%	0%	14.29%	1.000	0.773	0.500
NAP II: Announcements after the EC decision	3	0%	0%	0%	1.000	0.500	0.875
Phase III: Emissions caps	7	0%	0%	0%	1.000	0.500	0.773
Phase III: Auctioning rules	6	0%	0%	0%	1.000	0.656	0.656
Scope of the EU ETS	17	0%	0%	0%	1.000	0.686	0.500
Verification 2005	1	0%	0%	0%	1.000	0.500	1.000
Verification 2007	1	0%	0%	0%	1.000	0.500	1.000
Verification 2008	1	0%	0%	0%	1.000	1.000	0.500
Verification 2009	1	0%	0%	0%	1.000	1.000	0.500
Other announcements: UK	5	0%	0%	0%	0.375	0.969	0.188
Other announcements: Germany	1	0%	0%	0%	1.000	1.000	0.500
CITL-ITL linkage	2	0%	0%	0%	0.500	1.000	0.250
CERs	5	0%	0%	0%	1.000	0.813	0.500
COP/MOP meetings	4	0%	0%	0%	0.125	1.000	0.063

Table 3.14 Changes in option implied volatility

This table reports the results of Equation 3. Robust standard errors are used. The corresponding t-statistics are reported below the regression coefficients. *, **, *** refer to significance at the 1%, 5% and 10% level respectively.

Panel A: Aggregate event categories

	D_{-5}	D_{-4}	D_{-3}	D_{-2}	D_{-1}	D_0	D_{+1}	D_{+2}	D_{+3}	D_{+4}	R^2
NAP II announcements	-0.9920	-0.9210	-1.5621	0.3706	0.7016	0.8464	0.2436	1.4448	0.2050	-0.3369	4.21%
	-0.64	-0.59	-1.10	0.43	0.92	1.15	0.29	0.92	0.24	-0.63	
Phase III announcements	0.2886	0.1427	0.0432	0.0566	-0.2176	-0.0998	-0.1410	0.0507	-0.1190	-0.0045	1.04%
	0.47	0.26	0.11	0.24	-0.95	-0.41	-0.35	0.14	-0.35	-0.01	
Scope of the EU ETS	-0.9440**	-1.1371***	-0.6975	-0.1182	0.1427	0.5470	1.2680**	0.4944	0.3779	0.0668	15.64%
	-2.36	-1.72	-1.58	-0.21	0.40	1.23	2.27	1.13	0.77	0.13	
Verification events	0.5841	4.0916***	2.1222**	1.4589	0.7815	0.8374	-0.6376	-2.4575**	-3.3221**	-3.4585*	64.22%
	1.24	1.74	2.63	1.28	0.81	0.63	-1.20	-2.82	-2.18	-2.89	
Other announcements: UK and Germany	-0.2087	-0.1184	-0.0848	-0.0009	-0.1268	0.3064	-0.5899	0.5096**	-0.1122	0.4258	10.32%
	-1.03	-0.55	-0.38	-0.01	-0.26	0.99	-0.89	2.28	-0.31	0.42	
Kyoto offsets	-0.4338	-0.2295	-0.0449	0.1717	0.2083	0.1344	0.0694	-0.0097	-0.1782	0.3124	8.73%
	-1.02	-0.68	-0.21	0.8	1.41	0.82	0.42	-0.02	-0.6	0.96	
COP/MOP meetings	0.1483	-0.0150	0.3617*	0.4217*	0.4683**	0.1183	-0.0917	-0.4483**	-0.4883**	-0.4750**	56.17%
	0.33	-0.05	25.98	3.81	2.23	1.02	-0.83	-2.39	-2.52	-2.49	

Panel B: Sub-categories of events

	D_{-5}	D_{-4}	D_{-3}	D_{-2}	D_{-1}	D_0	D_{+1}	D_{+2}	D_{+3}	D_{+4}	R^2
NAP II: Leaked information	-0.3207*	-0.3787*	-0.1987*	0.2927	0.7565	0.6863	0.0882	-0.2994	-0.3268	-0.2994	32.91%
	-4.06	-13.64	-34.26	0.60	0.76	0.82	0.30	-0.46	-0.46	-0.41	
NAP II: Notification to the EC	-4.1636	-4.2043	-7.6943	2.3892	2.8673	2.7859	2.7635	2.9751	2.8429	-0.5617	2150%
	-0.50	-0.51	-1.25	0.63	0.79	0.76	0.75	0.82	0.78	-0.77	
NAP II: Additional information	2.5469	3.0291**	2.9192**	2.0525	1.6832	1.6344	-3.3595	-3.4694	-3.4694	-3.5670	64.73%
	1.75	3.12	2.70	1.05	0.73	0.69	-1.27	-1.37	-1.37	-1.47	
NAP II: Additional info to amended plan	0.3072***	0.2888***	0.3102***	0.3316	0.1790*	0.1556	0.0671	-0.2350	-0.4851***	-0.9193**	81.32%
	1.93	2.05	1.91	1.81	5.78	1.22	1.72	-0.89	-1.84	-2.90	
NAP II: Acceptance	-1.1145	-1.2808***	-1.5738*	-0.1898	-0.4233	-0.5408*	0.8295	1.1560*	1.2781***	1.8594***	72.90%
	-0.99	-2.20	-8.30	-0.21	-1.43	-6.98	0.81	8.34	2.14	2.03	
NAP II: After official decisions	-1.7728	-1.5876	-1.1706	-2.1593	-0.8694	0.1275	-0.0190	6.2574	0.3024	0.8914	28.37%
	-0.86	-0.80	-0.53	-1.09	-1.31	0.39	-0.06	0.91	0.38	0.90	
Phase III: Emissions caps	0.0135	0.1028	0.0853	-0.0267	0.0169	0.0885	0.0167	-0.1673	-0.2449	0.1152	0.58%
	0.01	0.14	0.14	-0.07	0.07	0.34	0.02	-0.27	-0.49	0.16	
Phase III: Auctioning	0.6095	0.1894	-0.0060	0.1538	-0.4912	-0.3195	-0.3249	0.3051	0.0280	-0.1441	6.01%
	0.73	0.21	-0.01	0.59	-1.20	-0.71	-0.72	0.82	0.06	-0.26	
Scope of the EU ETS	-0.9440**	-1.1371***	-0.6975	-0.1182	0.1427	0.5470	1.2680**	0.4944	0.3779	0.0668	15.64%
	-2.36	-1.72	-1.58	-0.21	0.40	1.23	2.27	1.13	0.77	0.13	
Verification events	0.5841	4.0916***	2.1222**	1.4589	0.7815	0.8374	-0.6376	-2.4575**	-3.3221**	-3.4585*	64.22%
	1.24	1.74	2.63	1.28	0.81	0.63	-1.20	-2.82	-2.18	-2.89	
Other announcements: UK	-0.2504	-0.1482	-0.0604	0.0826	0.0992	0.4546	-0.6398	0.4934***	-0.0901	0.0591	9.32%
	-0.98	-0.54	-0.21	0.81	0.18	1.29	-0.75	1.72	-0.19	0.05	
CITL-ITL linkage	0.0278	0.0339	-0.0729	0.2383	0.4611	0.4184	0.3116	-0.5673	-0.7413	-0.1096	12.84%
	0.02	0.03	-0.09	0.43	1.36	0.78	0.51	-0.36	-0.69	-0.56	
CERs	-0.6184***	-0.3349	-0.0337	0.1450	0.1071	0.0207	-0.0274	0.2134	0.0470	0.4811	26.59%
	-1.96	-1.44	-0.22	0.56	0.67	0.16	-0.26	1.01	0.30	1.10	
COP/MOP meetings	0.1483	-0.0150	0.3617*	0.4217*	0.4683**	0.1183	-0.0917	-0.4483**	-0.4883**	-0.4750**	56.17%
	0.33	-0.05	25.98	3.81	2.23	1.02	-0.83	-2.39	-2.52	-2.49	

3.7. Conclusions

This chapter presents the results of an event study conducted in order to detect significant price reactions following announcements related to different aspects of the EU ETS institutional design. A significant, albeit small in magnitude, market response was documented after multiple demand- and supply-side announcements, suggesting that they are in fact important for the carbon price dynamics.

The observed market reactions on the event days are, in their majority, in line with the initial expectation that announcements which suggest increases (decreases) in the supply of EUAs result in a negative (positive) price reaction while announcements which suggest increases (decreases) in the demand for EUAs result in a positive (negative) price reaction. All NAP I announcements are shown to have elicited a positive price reaction, suggesting that market participants saw these as good news events. As for Phase II NAPs, information releases before formal submission to the EC, submission to the EC, and additions to original and amended plans vary in sign and significance across the different time periods which are examined. Amendments of the original allocation plans are associated with positive event returns as the downward revisions of EUA allocations are factored into carbon prices. Contrary to Rotfuβ et al. (2009), NAP acceptances are not found to impact the carbon price dynamics. Announcements after the formal decisions of the EC do not meaningfully affect carbon prices either. All annual compliance events are shown to cause significant positive reactions, suggesting that the market may tend to overestimate the expected excess of EUAs in the system. As in Miclaus et al. (2008), verification events are found to have had the strongest impact on the carbon price formation.

Positive and mostly significant event returns are observed following announcements related to post-2012 emissions reduction targets, changes to the auctioning rules and the expanding scope of the ETS. Despite the importance of Kyoto offsets for the EUA market, announcements related to the CITL-ITL linkage and the CERs availability for compliance purposes have not resulted in significant event returns. The importance of Germany as a key player in the ETS is confirmed. COP/MOP events are associated with negative market responses as market participants factor in the inability of the international leaders to agree on a Kyoto successor.

In brief, investors are found to react to information about the institutional set-up of the EU ETS but they inaccurately assess the impact of the announcements on the prices of futures contracts with expirations in different trading periods of the scheme. Announcements related to Phase II and III are found to affect the prices of futures contracts expiring in both of these phases, which is in line with the transferability of allowances between these two periods. Contrary to expectations, however, these announcements also impact Phase I prices. In addition, some of the Phase I events impact Phase II futures (e.g. the verification event of 2005 results in significant event returns for the 2008 futures contract). This is inconsistent with the ban on inter-temporal banking and borrowing and leads me to believe that the market is not fully efficient yet.

The impact of the event dummies is found to be robust to the inclusion of explanatory variables to the univariate model. The multifactor model is shown to perform substantially better than the univariate one as fuel prices, the stock market and extreme weather explain a considerable part of the variability in carbon prices. However, no stable relationship is found between the carbon market and its fundamentals. It would appear that in the recessionary environment following the onset of the financial crisis, the presence of excess EUAs has led to a disconnect between the carbon market and its key price drivers. Evidence is also found to support the hypothesis that the carbon market has become less responsive to institutional disclosure following the start of the financial crisis. The poor explanatory power of the event dummies in the full-crisis subsamples (in both the univariate and multivariate regressions) is interpreted as a confirmation of the view that in the context of decreased industrial production and known EUA oversupply, announcements about the institutional framework of the scheme are less important to market participants.

Lastly, contrary to my expectations, I find no proof that the variance of returns increases following institutional announcements. Both the Brown-Forsythe and the sign test confirm earlier findings in the literature (Mansanet-Bataller and Pardo, 2009; Lepone et al., 2011) that institutional announcements have no impact on the variability of carbon returns. The examination of changes in option implied volatility, however, supports the hypothesis that uncertainty increases before scheduled events and decreases afterwards. The significant changes in implied volatility around the annual release of verified emissions data and the COP/MOP meetings confirm the importance of these events for the market players.

APPENDIX 3A CONSTRUCTION OF THE EUROPEAN WEATHER INDEX

In constructing the average temperature on an aggregate EU-wide level, I use daily mean temperatures in only those European countries which are covered by the ETS. The underlying logic is that extreme weather in these countries leads to excess demand for electricity, which in turn affects the carbon price. When the EU ETS was launched in 2005, all 15 countries which were then EU members were covered by the scheme. Cyprus and Malta began trading during Phase II of the ETS. Having been accepted to the EU in 2007, Bulgaria and Romania also joined the carbon market in its second trading period. During Phase II, three additional non-EU countries also linked up with the scheme. These were Iceland, Norway and Liechtenstein. Since the sample covers the period from April 2005 until June 2011, I limit the analysis of the average European temperature to these countries which have been covered by the scheme since its very beginning in 2005. Therefore, I disregard climatic data from Bulgaria, Romania, Cyprus, Malta, Norway, Liechtenstein and Iceland.

In addition, countries with little or no meteorological historical data were omitted from the sample. These included the Czech Republic (with mean daily temperature available from 1 station only), Belgium (0 stations), Hungary (0 stations), Luxembourg (1 station), Poland (2 stations), Slovakia (2 stations), Finland (3 stations) and Latvia (3 stations). Individual stations with large gaps in the data were removed from the countries remaining in the sample. 9 stations were removed from the Spanish sample, 6 were removed from the German data set, 2 from the Dutch data and 1 from Slovenian data. Only the stations with over 25% of missing observations were removed from the samples. All data is taken from the official European Climate Assessment & Dataset website, available at http://eca.knmi.nl/. Average historical monthly temperatures are calculated over the period 01/01/1985 – 31/12/ 2004.

An average monthly temperature is calculated for every country over the time period from January 1, 1985 through to December 31, 2004. The average monthly $T°_{i,\ mm/yy}$ is calculated where i is the country i = [Austria, Denmark, Estonia, France, Germany, Greece, Ireland, Italy, Lithuania, Netherlands, Slovenia, Spain and Sweden], *mm/yy* annotates the specific month in a given year. For example, the average 1986 January temperature in France is found as the arithmetic average of all the daily mean temperatures recorded in France over the specific time period January 1 – 31, 1986. A European Temperature Index is then created as the weighted mean of the constituent countries, where the weight given to each country corresponds to its population. The average EU monthly $T°_{mm/yy}$ is found as the weighted average of all the countries included in the dataset. The weight given to each country is proportional to its population. Therefore,

$$EU\ T°_{mm/yy} = \sum T°i, mm/yy * \frac{Population_i}{EU\ Population}$$

The average EU monthly T° over the entire period 1985 – 2004 is found by averaging the monthly estimates of the specific years. For example,

$$EU\ T°_{mm} = \frac{\sum EU\ T°i, mm/yy}{20}$$

Daily temperature deviations around the European mean are calculated for all months over the period April 22, 2005 – June 31, 2011. Positive deviations (extremely hot weather compared to the past 20 years) and negative deviations (extremely cold weather) are examined separately. Two extreme weather dummy variables are created. The variable

“Cold” captures winter days on which the temperature is three standard deviations lower than the 20-year average for that month. For the purposes of this chapter, winter is defined to include the months of December, January and February. The variable “Hot” captures at summer days on which the temperature is three standard deviations higher than the 20-year average for that month. Summer here is defined to include the months of June, July and August. Extremely hot and cold events are examined separately in order to capture an asymmetric response, if any, in the prices of carbon. The “Cold” and “Hot” variables are binary dummy variables which take on values of 1 for days with extreme weather and 0 otherwise. 77 extreme weather events are identified over the sample period – 54 extremely hot days and 23 extremely cold days.

APPENDIX 3B REGRESSIONS WITH NO SAME-DAY EVENTS ONLY

Table 3.15 Univariate analysis: before and during the financial crisis

Only events with no same-day announcements are used for the analysis. The table reports the regression results of Equation 1. The sample is split into pre-crisis (22/04/2005 - 16/08/2007) and full-crisis (17/08/2007 - 30/06/2011) subsamples. The dependent variable is: 1) log-return of nearest-to-expiry EUA futures contracts, 2) near-phase EUA futures. Robust Newey-West HAC standard errors are used.

Events	Pre-crisis subsample		Full-crisis subsample	
	Intraphase R_e	Interphase R_e	Intraphase R_e	Interphase R_e
Intercept (R_{ne})	-0.0070*	0.0009	-0.0009	-0.0003
NAP I: Notification of additional information	0.0260*	0.0192*†		
NAP I: Acceptance	0.0618*	0.0531*†		
NAP I: Rejection	0.0052**	-0.0195*†		
NAP II: Leaked info before formal submission	0.0012	-0.0044	0.0157*	0.0137*
NAP II: Notification to the EC	0.0099	0.0061	-0.0296*	-0.0304*
NAP II: Notification of additional information	-0.0198**	-0.0088**	0.0009	0.0060*
NAP II: Notification of amended plan	0.0316	-0.0059	0.0076*	0.0039
NAP II: Additional information to amended plan	-0.0418***	-0.0056	-0.0267	0.0041
NAP II: Acceptance	-0.0192	0.0196**	-0.0204	-0.0040
NAP II: Rejection			-0.0032*	-0.0064*
EC announcement after its formal decision	-0.1396*	-0.0009	-0.0063	-0.0063
NAP II: Withdrawal of a plan	-0.0262*	-0.0633*		
Phase III: Emissions caps	0.0644***	-0.0133	0.0090	0.0088
Phase III: Auctioning rules			0.0145*	0.0132*
Scope	-0.0110	0.0011	-0.0056	-0.0112**
Verification 2005	-0.0101	-0.0398		
Verification 2007			0.0401*	0.0395*
Verification 2008			-0.0003	-0.0118
Verification 2009			0.0210*	0.0180*
Other announcements: UK			-0.0022	-0.0013
Other announcements: Germany			-0.0028	-0.0042
CITL – ITL linkage			0.0147	0.0167**
CERs			0.0007	-0.0008
COP/MOP	-0.0024	-0.0045	-0.0013	-0.0019
R-squared	4.06%	4.93%	0.82%	2.15%
Adjusted R-squared	1.57%	2.46%	-1.12%	0.24%

*, **, *** refer to significance at the 1%, 5% and 10% level respectively
† indicates that although a price is quoted on the ECX, trading in these futures hasn't started yet

Table 3.16 Univariate analysis: Bai-Perron structural breaks.

This table reports the regression results of Equation 1. Only events with no same-day announcements are used for the analysis. The sample is split into three subsamples - (22/04/2005 - 26/12/2006), (27/12/2006 - 21/06/2007) and (22/06/2007 - 30/06/2011) according to the Bai-Perron algorithm. The dependent variable is: 1) log-return of nearest-to-expiry EUA futures contracts, 2) near-phase EUA futures. Robust Newey-West HAC standard errors are used.

Events	Subsample 1		Subsample 2		Subsample 3	
	Intraphase R_e	Interphase R_e	Intraphase R_e	Interphase R_e	Intraphase R_e	Interphase R_e
Intercept (R_{ne})	-0.0018	0.0006	-0.0339*	0.0025	-0.0008	-0.0003
NAP I: Additional information	0.0209*	0.0195*†				
NAP I: Acceptance	0.0567*	0.0533*†				
NAP I: Rejection	0.0000	-0.0192*†				
NAP II: Leaked information	-0.0019	-0.0047	0.0029	0.0020	0.0156*	0.0137*
NAP II: Notification to the EC	0.0002	0.0047	0.0664	0.0154	-0.0298*	-0.0304*
NAP II: Additional information	-0.0135	-0.0043	-0.0069	-0.0119	-0.0035	-0.0178***
NAP II: Amended plan	-0.0204*	-0.0093*	0.0703***	-0.0066	0.0075**	0.0039
NAP II: Additional Information to amended plan			-0.0190	-0.0048	-0.0306	-0.0042
NAP II: Acceptance			0.0114	0.0269*	-0.0250***	-0.0046
NAP II: Withdrawal of a plan	-0.0313*	-0.0631*		-0.0025	-0.0033*	-0.0064*
EC announcement after its formal decision			-0.1127*		-0.0065	-0.0063
Phase III: Emissions caps			0.0914**	-0.0149	0.0089	0.0088
Phase III: Auctioning rules					0.0143*	0.0132*
Scope	0.0124	0.0015	-0.0837	-0.0010	-0.0057	-0.0112**
Verification 2005	-0.0152	-0.0396				
Verification 2007					0.0399*	0.0395*
Verification 2008					-0.0005	-0.0118
Verification 2009					0.0208*	0.0180*
Other announcements: UK					-0.0023	-0.0013
Other announcements: Germany					-0.0030	-0.0042
CITL – ITL linkage					0.0146	0.0166**
CERs					0.0006	-0.0008
COP/MOP	-0.0075	-0.0042			-0.0014	-0.0019
R-squared	1.73%	4.98%	8.37%	6.93%	1.07%	2.27%
Adjusted R-squared	-0.86%	2.47%	1.20%	-0.35%	-0.78%	0.44%

*, **, *** refer to significance at the 1%, 5% and 10% level respectively
† indicates that although a price is quoted on the ECX, trading in these futures hasn't started yet

Table 3.17 Multivariate analysis: before and during the financial crisis.

The table reports the regression results of Equation 1. Only events with no same-day announcements are used for the analysis. The sample is split into pre-crisis (22/04/2005 - 16/08/2007) and full-crisis (17/08/2007 - 30/06/2011) subsamples. The dependent variable is: 1) log-return of nearest-to-expiry EUA futures contracts, 2) near-phase EUA futures. Robust Newey-West HAC standard errors are used.

	Pre-crisis subsample		**Full-crisis subsample**	
Events	**Intraphase R_e**	**Interphase R_e**	**Intraphase R_e**	**Interphase R_e**
Intercept (R_{ne})	-0.0074*	0.0007	0.0055	-0.0003
Oil	0.3835*	0.1889**	0.3331***	0.1555*
Gas	0.1396*	0.0661*	0.2168**	0.0770*
Equity	-0.2714	-0.1051	-0.1675	0.2066*
Cold	0.0119**	0.0060	-0.0182***	-0.0109**
Hot	0.0089***	0.0011	-0.0031	0.0053
NAP I: Notification of additional information	0.0274*	0.0199*†		
NAP I: Acceptance	0.0509*	0.0494*†		
NAP I: Rejection	0.0178*	-0.0136*†		
NAP II: Leaked information before formal submission to the EC	-0.0006	-0.0048	0.0078	0.0128*
NAP II: Notification to the EC	0.0039	0.0035	-0.0038	-0.0049
NAP II: Notification of additional information	-0.0188**	-0.0081***	0.0005	0.0030**
NAP II: Notification of amended plan	0.0362	-0.0035	0.0067	0.0046*
NAP II: Notification of additional information to amended plan	-0.0394***	-0.0045	-0.0474	0.0013
NAP II: Acceptance	-0.0258	0.0164**	-0.0293	-0.0041
NAP II: Rejection			-0.0093***	-0.0070*
EC announcement after its formal decision	-0.1376*	-0.0004	-0.0101	-0.0056
NAP II: Withdrawal of a plan	-0.0307*	-0.0655*		
Phase III: Emissions caps	0.0704**	-0.0104	-0.0008	0.0067
Phase III: Auctioning rules			0.0066	0.0123*
Scope	-0.0112	0.0010	-0.0130	-0.0098**
Verification 2005	-0.0079	-0.0387		
Verification 2007			0.0194**	0.0303*
Verification 2008			-0.0039	-0.0092
Verification 2009			0.0136*	0.0131*
Other announcements: UK			-0.0019	0.0040
Other announcements: Germany			-0.0101	-0.0064
CITL – ITL linkage			-0.0272	0.0022
CERs			-0.0082	-0.0014
COP/MOP	-0.0041	-0.0054	-0.0021	0.0033
R-squared	7.30%	7.62%	0.44%	12.98%
Adjusted R-squared	4.00%	4.34%	-2.06%	10.80%

*, **, *** refer to significance at the 1%, 5% and 10% level respectively
† indicates that although a price is quoted on the ECX, trading in these futures hasn't started yet

Table 3.18 Multivariate analysis: Bai-Perron structural breaks.

This table reports the regression results of Equation 1. Only events with no same-day announcements are used for the analysis. The sample is split into three subsamples - (22/04/2005 - 17/12/2006), (18/12/2006 - 04/04/2007) and (05/04/2007 - 30/06/2011) according to the Bai-Perron algorithm. The dependent variable is: 1) log-return of nearest-to-expiry EUA futures contracts, 2) near-phase EUA futures. Robust Newey-West HAC standard errors are used.

Events	Subsample 1		Subsample 2		Subsample 3	
	Intraphase R_e	Interphase R_e	Intraphase R_e	Interphase R_e	Intraphase R_e	Interphase R_e
Intercept (R_{ne})	-0.0022	0.0004	-0.0257***	0.0017	-0.0020***	0.0000
Oil	0.2627*	0.1953**	1.2107**	0.1397	0.1643*	0.1602*
Gas	0.0903*	0.0478*	0.7056*	0.2865*	0.1005**	0.0726*
Equity	-0.0871	-0.3901**	-0.8380	0.3522	0.2867*	0.2141*
Cold	0.0080***	0.0059			-0.0099	-0.0112**
Hot	0.0064	0.0040			0.0011	0.0022
NAP I: Additional information	0.0218*	0.0203*†				
NAP I: Acceptance	0.0494*	0.0472*†				
NAP I: Rejection	0.0078**	-0.0112*†				
NAP II: Leaked information	-0.0032	-0.0062	0.0076	0.0056	0.0163*	0.0123*
NAP II: Notification to the EC	-0.0035	0.0029	0.0396	0.0162	0.0034	-0.0050***
NAP II: Additional information	-0.0117	-0.0029	-0.0134	-0.0107	-0.0287	-0.0097
NAP II: Amended plan	-0.0127*	-0.0035	0.0753	0.0029	0.0095*	0.0042*
NAP II: Additional information to amended plan			-0.0130	0.0033	-0.0405	-0.0027
NAP II: Acceptance			-0.0125	0.0200***	-0.0334***	-0.0002
NAP II: Rejection					-0.0028**	-0.0073*
NAP II: Withdrawal	-0.0340*	-0.0662*				
EC announcement after its formal decision					-0.0290	-0.0057
Phase III: Emissions caps			0.1056**	-0.0074	0.0081	0.0067
Phase III: Auctioning rules					0.0151*	0.0122*
Scope	0.0140	0.0010	-0.0416	0.0031	-0.0046	-0.0095**
Verification 2005	-0.0134	-0.0389				
Verification 2007					0.0304*	0.0298*
Verification 2008					0.0037	-0.0094
Verification 2009					0.0159*	0.0125*
Other announcements: UK					0.0054	0.0038
Other announcements: Germany					-0.0050	-0.0067
CITL – ITL linkage					-0.0032	0.0026
CERs					0.0013	-0.0018
COP/MOP	-0.0087*	-0.0042			0.0054	0.0031
R-squared	4.51%	7.70%	28.79%	28.14%	5.84%	12.20%
Adjusted R-squared	0.71%	4.03%	16.16%	15.40%	3.68%	10.19%

*, **, *** refer to significance at the 1%, 5% and 10% level respectively
† indicates that although a price is quoted on the ECX, trading in these futures hasn't started yet

CHAPTER 4 DOES CO_2 EMISSIONS PERFORMANCE MATTER? EVIDENCE FROM GERMANY AND THE UNITED KINGDOM

"…What is a concern from social perspective is not always a concern from financial perspective."

(Galema et al., 2008)

4.1. INTRODUCTION

Investors are becoming increasingly concerned with the non-financial aspects of a company's behaviour, such as the impact of its operations and products on the environment. Investment management companies have launched funds with environmental remits in response to the growing demand for ethical and green businesses. There are so-called dark green funds, such as Kames Capital Ethical Equity, which do not invest in companies whose activities are judged to be environmentally unsound or are "in energy intensive industries which are not tackling the issue of climate change"[25]. Europe's commercial banks have also recognized the problem of climate change and have introduced policies to exert pressure on polluters which emit high levels of carbon into the atmosphere. HSBC, Standard Chartered, BNP Paribas and Credit Agricole have adopted new standards for the financing of coal-fired power plants, whereby dirty plants with emissions intensities above a certain threshold will not qualify for financing (Financial Times, 2011). Companies themselves have begun to implement measures to reduce their carbon footprint - from energy consumption savings to procurement of electricity for the firm's own energy use from renewable sources. Some firms, National Grid being one

[25] Kames Capital Ethical Equity Fund, <http://www.kamescapital.com/ethicalequity.aspx?taxID=252>

example[26], even offer monetary rewards to executives and environmental managers for successful achievement of internally set up emissions reduction targets. As awareness of climate change has seemingly gained momentum in society at large, one could argue that the carbon performance of companies should become a standard component of investment analysis.

The objective of this chapter is to assess whether the carbon performance of companies constitutes a source of value-relevant information for the financial market. I seek to answer a simple question - do firm-specific carbon emissions data convey valuable information to investors? My focus is the relationship between carbon emissions and stock performance for German and British publicly-traded companies regulated under the EU ETS. The change in financial performance is assessed through the stock price response upon the scheduled release of mandated emissions information. I also test whether the data released at the annual verification events play a more important role for carbon-intensive companies such as electricity producers.

In addition, the success of the ETS from a social perspective is considered. I evaluate the environmental effectiveness of the scheme by examining whether companies tend to de-carbonize their operations following negative price reactions after the publication of their actual emissions. This issue is particularly relevant, especially in light of developments in the U.S. sulphur market which was briefly discussed in Section 3.6.1.1.B. Although the sulphur trading scheme was largely seen as a success from a financial perspective (the market was liquid and trading was active), regulatory authorities deemed the emissions reductions it achieved as insufficient to remedy the targeted environmental problem. As a

[26] Carbon Disclosure Project, <www.cdproject.net>

consequence, regulatory standards governing sulphur emissions at a firm-level were introduced[27], which led to a rapid decline in emissions trading and the de-facto demise of the scheme (Chan et al., 2012).

As carbon emissions represent one dimension of the firm's environmental performance, the contribution of this chapter is two-fold. It adds to the growing literature on the relationship between the environmental and financial performance of firms and it also adds to the scant firm-level analysis of the carbon market. I use a unique set of manually-collected data on the carbon performance of firms and document the impact of verified emissions publication on their returns in an event study framework. In addition, a panel data analysis is performed in order to identify the determinants of the observed market reactions on the event day. By focusing on publicly-traded firms with various activities, I am able to document the impact of the ETS across industries. Since all covered companies are affected simultaneously by the publication of the emissions reports, event clustering is present in the data set. To prevent misstatements of the impact on the stock prices, a Seemingly Unrelated Regressions (SUR) methodology is employed and event days are parameterised with dummy variables.

Significant market reactions to the verified emissions data disclosures are found in only one out of the six verification events over the period 2005 -2011 which suggests that investors do not perceive carbon performance as important enough to be priced into firm valuations yet. The level of freely allocated allowances and actual emissions during the year are shown to be insignificant in explaining the observed stock price responses. I find some support for the hypothesis that the emissions reports lead to a stronger market

[27] See footnote 24 in Section 3.6.1.1.B

reaction in companies with high carbon-intensive activities. No statistically significant proof is found that the market reacts differently towards environmental leaders and laggards upon disclosure of their carbon emissions data. Corporate carbon performance does not seem to be affected by the publication of emissions reports either. I conclude that, as it stands today, the EU ETS is not meeting the socially desirable objective of promoting the transition to a low-carbon economy.

The relevant literature review is discussed in Section 4.2. The testable hypotheses are formulated in Section 4.3. The methodology is discussed in Section 4.4, followed by sample selection and data collection issues in Section 4.5. Discussion of the results and conclusions follow.

4.2. Literature review

4.2.1. Financial performance and environmental information

There is a growing body of research on the relevance of corporate environmental performance for firm valuation. Some authors focus on short-term indicators of financial performance like changes in stock prices upon public provision of environmental data (Shane and Spicer, 1983; Khanna et al., 1998). Others link environmental disclosure and long-term financial performance by studying changes in the cost of equity capital (Clarkson et al., 2010; Plumlee et al., 2010). While the exact nature of the relationship between financial and environmental performance remains a bone of contention for academics, there is some evidence that integrating environmental information in the valuation process can positively impact investment returns. For example, eco-efficient stocks are found to outperform their less eco-efficient counterparts by 2 - 8% on an annualized basis, even after adjusting for market risk, industry specifics and investment style (Derwall et al., 2004). Also, there is a growing consensus on the increasing importance of environmental accounting disclosures (Blacconiere and Patten, 1994; Hamilton, 1995).

Much of the recent research has focused on the value-relevance of voluntary environmental reporting. In spirit, however, this chapter is closer to studies which examine the impact of legislatively mandated environmental reports. Examples of such reports are the pollution-level studies conducted by the Council of Economic Priorities (analysed by Shane and Spicer, 1983) and the U.S. Toxic Release Inventory (TRI) reports (researched by Hamilton, 1995; Konar and Cohen, 1997; Khanna et al., 1998). Hamilton (1995) examines the effectiveness of TRI reports as a regulatory tool. The author documents significant abnormal returns equivalent to an average loss in market value of $4.1 million on the day of the initial TRI data release in June 1989. Firms with a higher level of emissions, greater number of released pollutants and a larger workforce are found more likely to receive media coverage. For these firms, the abnormal losses are $6.2 million on the event day. With regards to the determinants of abnormal returns, Hamilton finds that investors respond to the number of pollutants released by a company (whereby, for an additional chemical, the market value of companies drops by an additional $230,000) rather than the actual levels of reported emissions. Unfortunately, Hamilton (1995) makes no correction for the cross-correlation between the residuals which is likely to arise due to the fact that TRI reports for several firms are published on the same day.

Konar and Cohen (1997) focus on the effectiveness of TRI reports in altering corporate environmental behaviour. Firms which experience negative abnormal returns following the initial release of data in 1989 are found to subsequently reduce their emissions by more than their competitors. Of the 40 firms whose market value declined in 1989, 32 firms (80%) had lower emissions than their competitors in 1992. Again, no correction for the cross-correlations in the data is made. Khanna et al. (1998) examine the impact of 6 consecutive report publications on 91 publicly-traded U.S. firms in the chemical industry over the period 1989 – 1994. Negative price reactions are documented following deterioration of a company's environmental performance relative to its own past performance or relative to competitors. The authors find firm size and R&D to be important determinants of the observed abnormal returns. No statistically significant reduction is found in the levels of waste generated by companies, thereby questioning the environmental effectiveness of the TRI. A shortcoming of the analysis is the use of absolute emissions rather than emissions intensity in the evaluation of environmental performance.

4.2.2. Economic consequences of EU ETS compliance

To my knowledge, there is yet no published paper which examines the relationship between carbon emissions data and financial performance through the perspective of short-term stock price reactions following repeat ETS report publications. Recent research has predominantly attempted to quantify the economic impact of the scheme on covered companies by analysing changes in their profitability. Since the onset of the cap-and-trade programme, there have been persistent debates about its consequences on firm competitiveness. Many worry that the unilateral nature of the scheme will undermine the competitiveness of European industries and lead to market share losses to their non-regulated foreign counterparts. There are concerns that the net loser from the ETS will be firms in highly energy-intensive industries; firms with strong international competition (and thus lesser ability to pass-through carbon costs to customers) and finally, firms which are not able to abate internally at a low cost (Oberndorfer and Rennings, 2007; Smale et al., 2006). All of these issues have been examined extensively (Quirion and Demailly, 2006; Smale et al., 2006; Oberndorfer and Rennings, 2007; Alexeeva-Talebi and Anger, 2007; Anger and Oberndorfer, 2008; Grubb et al., 2009).

Some of the studies are conducted at a sectoral level - for the European electricity industry (Neuhoff et al., 2006) for the cement (Quirion and Demailly, 2006) and for the iron and steel sectors (Demailly and Quirion, 2008). Only a modest negative impact on the competitiveness of these sectors is documented relative to a business-as-usual scenario (for a literature review of simulation-based studies, see Oberndorfer and Rennings, 2007). With regards to the impact of carbon regulation at the firm-level, in a study of 419 ETS-covered public and private German companies, Anger and Oberndorfer (2008) find no evidence that the different levels of freely allocated EUAs to verified emissions have affected firm profitability and employment. They attribute the results to generous allocations of allowances during Phase I and resulting weak compliance buying. Grubb et al. (2009) find evidence to the contrary and report that the impact of emissions trading on profitability depends on the relative allocation of grandfathered allowances. For 2,101 European firms over the period 2005-2008, Abrell et al. (2011) document a strong correlation between the amount of allowance allocations and the reduction effort. Companies which have received excess EUAs are shown to undertake less internal abatement relative to companies which received less allowances than their needs.

4.2.3. Relationship between CO_2 prices and stock prices

Several studies report a significant relationship between carbon prices and the stock prices of ETS-covered companies, particularly for power companies (Oberndorfer, 2009; Veith et al., 2009; Bushnell et al., 2009). While the scheme has had a limited impact on the cost structure of power companies because of generous free EUA allocations, electricity companies have overcompensated for the opportunity cost of carbon by raising electricity prices more than proportionately and earning regulatory rents (Smale et al., 2006; Bushnell et al., 2009). Because energy producers operate in generally isolated domestic markets, it makes it relatively easy for them to pass on the carbon costs to their customers. While there is no consensus over the exact role the electricity market structure plays in determining the degree of cost pass-through (Sijm et al., 2006; Smale et al., 2006; Zachmann and von Hirschhausen, 2008) there is strong evidence of electricity price increases to incorporate the price of carbon (Zachmann and von Hirschhausen, 2008; Oberndorfer, 2009; Veith et al., 2009). For energy-intensive companies, this means that in addition to the direct costs of buying allowances and/or reducing their carbon footprint, they also have the indirect costs of higher electricity bills (Hoffmann, 2007).

Oberndorfer (2009) models the returns of an equally-weighted portfolio made up of the 11 largest publicly-traded European electricity producers as a function of the broad market, carbon, electricity and fuel prices. The author emphasizes the importance of using oil and gas as explanatory variables because of their dual role as price drivers for both energy stocks and carbon allowances. A time- and country-specific statistically significant positive association between the returns of power companies and carbon is reported. Veith et al. (2009) examine 22 large European electricity producers, not all of which are regulated by the ETS, and confirm Oberndorfer's (2009) conclusion that stock prices have been positively associated with carbon prices during Phase I. The returns of power companies are modelled as a function of the market portfolio and carbon only but the findings are shown to be robust to the addition of oil, gas, the electricity market structure and its regulatory framework as independent variables. However, the estimated positive correlation between the prices of power companies and carbon breaks down when the proportion of fossil electricity generation is accounted for.

Lastly, Bushnell et al. (2009) relate the returns of carbon certificates and ETS-covered companies in an event study. The stock prices of 90 companies across various industries are examined following the sharp drop of the carbon price on April 25th, 2006 when information was leaked prior to the first official disclosure of emissions data by the EC. A statistically significant positive link between carbon prices and stock prices of covered entities is reported for both carbon-intensive companies as well as energy-intensive companies with little exposure to international trade. Abnormal returns are estimated as parameterized dummy coefficients in an ordinary least squares framework. The return-generating model, however, employs the broad market as the only source of priced risk, possibly producing abnormal return estimates which may be driven by an omitted risk factor.

4.3. HYPOTHESES DEVELOPMENT

The underlying assumption of this chapter is that carbon performance has significant implications for the valuation and future cash flows of ETS-covered companies. Several reasons can be put forward to justify this proposed association. These include, but are not limited to, future environmental liabilities and abatement expenditures, concerns over negative publicity and adverse impact on the reputation of the firm, and the regulatory framework.

First, compliance with the scheme presents a source of financial risk for covered companies. Regulated firms can choose to either abate internally or purchase allowances in the market. Both of these options are associated with cash outflows. Stringent emissions caps and a move away from grandfathering to auctioning of allowances from 2013 onwards imply that costs of compliance will go up, thereby increasing the operating costs for the business and lowering the expected profitability. Second, there are risks associated with potential changes in the set-up of the cap-and-trade programme. Uncertainty about the future regulatory and institutional framework undermines the signal embedded in carbon prices and fails to provide incentives for long-term investments in low-carbon technologies. Third, there is non-compliance risk which can be manifested as a financial loss[28] or an intangible loss of credibility and reputation. Inability of firms to meet publicly communicated reduction targets may lead to increased criticism from environmental industry watchers and the alienation of environmentally-aware customers.

In this chapter, I aim to test whether investors price carbon emissions into firm valuations. With no prior information about the amount of emissions which can be anticipated from individual firms[29], 2005 is used as a benchmark year. Thus, expected emissions for the first ETS compliance event are taken to be equal to the amount of freely allocated allowances to every company. For the rest of the verification events, expected emissions are estimated as

[28] For a description of the monetary penalties for companies which fail to surrender EUAs corresponding to their actual emissions during the year, refer to Section 3.2.1.2 of Chapter 3.

[29] Prior to the launch of the EU ETS, any available carbon performance data was voluntarily disclosed and usually in a “soft”, non-monetary context. Actual emissions were rarely disclosed.

a projection of the actual emissions from the previous reporting period[30] adjusted for changes in sales. Adjustments are made for the change in revenue to reflect higher (lower) emissions associated with expanding (shrinking) economic activity. The proposed model implicitly assumes that covered companies undertake the same internal abatement from one year to the next. Two alternative hypotheses related to investors' reactions on the event day are tested.

H1: Companies which emit less than what the market anticipates are associated with positive abnormal returns, and companies which emit more are associated with negative abnormal returns.

The rationale is that investors react to news about exactly how much a firm emits above or below expectations. The incremental information conveyed to the market on the event day is the unexpected level of emissions. Actual emissions below the level of expected emissions are viewed as good news and actual emissions in excess of anticipated emissions are seen as bad news by the market. Unanticipated excess allowances represent a profit component which needs to be factored into firm value while unanticipated shortages of EUAs are an unaccounted for cost component. As allowances can be sold (bought) in the market for cash, they can represent an immediate cash inflow (outflow) for covered companies. Also, they can be banked (borrowed) for use in a later compliance period, creating an inter-temporal profile of benefits (costs).

H2: Companies which were anticipated to be net short of allowances but ended up in a net long position experience positive abnormal returns, and vice versa

[30] In cases where the number of installations which a firm is responsible for changes, this implies keeping the ratio of actual-to-allocated EUAs constant and multiplying it by the new amount of freely allocated allowances.

The underlying assumption is that investors react to unanticipated changes in the net position of companies rather than to discrepancies between the levels of actual and expected emissions. A negative price reaction is expected for companies which, contrary to prior belief, report a shortage of emissions certificates. Positive market reaction is anticipated for firms which are expected to be short of allowances but in reality end up on the long side. The rationale is that even if a company exceeds expected emissions levels, if the firm's net overall position doesn't change, no incremental information is contained in the emissions data release. The expectations are summarized graphically in Figure 4.1 below.

Figure 4.1 Investor reactions upon unforeseen changes in a firm's net position
This figure graphically depicts the expectations of the investors' reactions at the news of unanticipated changes in the firm's net position. Net position is defined as the difference between freely allocated allowances and verified emissions.

		Actual net position	
		Short	Long
Expected net position	Short	No news	Good news
	Long	Bad news	No news

Both Hypotheses 1 and 2 are based on the premise that the release of verified emissions data constitutes news to the market. Because a firm's EUA position can be measured in monetary terms, annual compliance events should enable market participants to adjust their assessment of firm values. And because data on the actual emissions of these companies is released only at the time of the emissions report publications, these should constitute market-moving events. If, however, information about the emissions of a certain company is leaked prior to the formal report publication, the event will no longer represent a true shock to the market and the observed stock price reaction will be understated. Testing for information leakage and significant price moves on the days surrounding report publications represents an opportunity for future research. A second caveat to the analysis presented in this chapter is the model used to describe investors' expectation formation processes. Although I propose two alternative models of possible behaviour, I acknowledge that the approach investors take in forming expectations about a firm's emissions level may significantly differ from my assumptions. Therefore, the results and conclusions reported in this chapter are entirely conditional upon the validity of the employed expectation formation processes and the degree to which they reflect actual investment behaviour.

Proceeding with the testable hypotheses, I also argue that the association between firm value and emissions performance is stronger for companies in carbon-intensive industries.

H3: The incremental information contained in ETS reports plays a more important role for companies in carbon-intensive industries.

The EU ETS has a differential impact on covered entities whereby firms in industries with low reduction targets and/or generous allocations of free EUAs are favoured by the scheme while firms in sectors with tight reduction targets and/or small amounts of freely granted EUAs are at a disadvantage (Anger and Oberndorfer, 2008). Carbon-intensive companies bear considerable financial risks, particularly in the context of tightening emissions targets and rising EUA prices. For these companies, future liabilities associated with ETS compliance might meaningfully affect investment returns. For less carbon-intensive industries where carbon performance is not a key company consideration, market participants may be less concerned with the ETS data. This hypothesis is in line with Derwall et al. (2004) who report smaller eco-efficiency premia for stocks of firms in environmentally-sensitive industries over those in not so sensitive industries. They rationalize this by suggesting that in environmentally-sensitive industries "eco-efficiency is arguably a significant driver of future corporate performance" (p.16) so investors are more likely to incorporate the information in their valuations.

H4: Market reactions are positively associated with the amount of freely allocated allowances and negatively associated with the amount of actual emissions

A positive association is expected between the stock price reaction and the amount of freely allocated allowances, as these represent an asset on the company's balance sheet. As already discussed, firms can sell the certificates in the market realising immediate financial gains or use them for compliance purposes, avoiding the need to buy EUAs at a later time. The expected relationship between verified emissions and abnormal returns is negative. As a firm's actual emissions increase, it must purchase allowances in the open market or borrow inter-temporally from its following year allocations. The net position of the company and the allocation factor are also used to explain the observed market reactions on the event day. The firm's net position is estimated as the difference between allocated and actual emissions and the allocation factor is estimated as their ratio (Anger and Oberndorfer, 2008; Abrell et al., 2011). Both of these measures describe whether a firm emits within its freely granted quota. The rationale for using them is that from the perspective of the financial markets, what is important is how much a covered company is net long or short. A positive relationship between the stock price response and the allocation factor (net position) is hypothesized.

In the last part of the analysis, the focus is on the social utility of the ETS. As noted by Point Carbon (2010), "[…] a regulatory market such as the EU ETS cannot remain politically viable unless companies are shown to reduce their GHG emissions" (p.4). The history of the Unites States' sulphur emissions trading scheme is a testament to this view.

H5: Negative abnormal returns lead companies to improve their carbon performance

I test whether firms which experience negative returns following the release of verified emissions data tend to reduce their emissions intensity in the following year. The objective is to provide empirical evidence on whether the EU ETS has the intended economic and social effects of incentivizing companies to abate internally. Emissions intensity is selected as a measure of carbon performance over the alternative of absolute emissions. Some companies open new installations and close existing ones over time and a change in the overall level of emissions may not necessarily reflect an improvement or deterioration in the carbon performance of a company. Also, by default large firms emit more than small firms in any given industry due to the sheer volume of their operations. By scaling carbon emissions by net sales, companies of different size are levelled.

H6: Disclosure of verified emissions data induces negative abnormal returns in carbon laggards and positive abnormal returns in carbon leaders

I also test whether share price incentives exist for covered companies to alter their carbon performance. If the ETS is an effective environmental policy, a differentiated market reaction is expected for firms which continue to pollute at the same rates and firms which seek to decrease the carbon emissions from their installations. While companies in environmentally-sensitive industries tend to be among the biggest CO_2 emitters (see Table 4.3 in Section 4.6), firm valuations should be conditioned on the firm's abatement efforts. Increasing emissions intensity signals higher future costs of compliance and, possibly, a loss of competitiveness. Decreasing emissions intensity positions firms better in the eyes of the shareholders, regulators, and society as a whole. Carbon leaders are defined as those companies which decrease the emissions intensity of their operations, and carbon laggards as those which increase it. The hypothesis is that the financial market rewards the former and punishes the latter.

4.4. METHODOLOGY

4.4.1. EVENT STUDY SET-UP

According to the market efficiency hypothesis, prices instantaneously incorporate new information as it becomes available. Thus, at any time market prices reflect asset fair values. While event studies are a common technique employed in the finance literature, there are no hard and fast rules when it comes to the design of the study. The dataset in this chapter is afflicted with event clustering because the report publications take place at the same calendar time for all firms. This suggests that cross-sectional dependence in the individual firm error terms may be present. It is well-documented in return-based studies that problems in inference exist when the data are cross-sectionally dependent (Bernard, 1987).

Traditional event study methods, such as OLS regression, are based on the premise of independently and identically distributed residuals. Violations of the underlying assumptions lead to misstatements of the standard errors and possibly incorrect inferences in hypotheses tests. To deal with the issue of contemporaneously correlated firm error terms, some researchers have chosen to combine firms in a portfolio and use portfolio returns in their event studies (e.g. Blacconiere and Patten, 1994). This approach is not practical for the purposes of this chapter as the aim is to identify cross-sectional differences in market reactions associated with firm-specific characteristics of the regulated entities. Bernard (1987) identifies several approaches for dealing with cross-sectional dependence, among which I select Zellner's (1962) Seemingly Unrelated Regressions (SUR) as the most suited for this analysis. The SUR technique has been used in several studies of regulatory change and its impact on asset prices (Binder, 1985a,b; Schipper and Thompson, 1983, 1985; Sefcik and Thompson, 1986; Brown et al., 2004; Betzer et al., 2011).

The number of time series observations and the calendar time frames are identical for all firms analysed here. The system of stacked equations for British and German companies is estimated jointly as seemingly unrelated regressions. The return-generating model for UK companies is:

$$R_{i,t} = \alpha_i + \beta_{i,1}R_{FTSE,t} + \beta_{i,2}R_{EUA,t} + \beta_{i,3}R_{Electricity,t} + \beta_{i,4}R_{FOREX,t} + \sum_{a=1}^{A}\gamma_{i,a}D_{at} + u_{i,t} \quad (1)$$

The return-generating model for German companies is:

$$R_{i,t} = \alpha_i + \beta_{i,1}R_{DAX,t} + \beta_{i,2}R_{EUA,t} + \beta_{i,3}R_{Electricity,t} + \beta_{i,4}R_{FOREX,t} + \sum_{a=1}^{A}\gamma_{i,a}D_{at} + u_{i,t} \quad (2)$$

where *t* refers to the time period

$R_{i,t}$ is the continuously compounded return of firm *i* (*i* = 1,..., *N*) at time *t*

$R_{FTSE,t}/R_{DAX,t}/R_{EUA,t}\ /R_{Electrcity,t}/R_{FOREX,t}$ is the continuously compounded return at time *t* of FTSE All Share/DAX30/carbon/electricity/exchange rates as defined in Table 4.1 of Section 4.5.4.

The dummy variable $D_{a,t}$ takes on the value of 1 for each of the annual verification events and 0 otherwise. Thus, the return-generating process is conditioned on the occurrence or non-occurrence of the verification event. $\gamma_{i,a}$ is the abnormal return experienced by company i over each verification event a=1,..,A. Two event windows are used. For the shorter event window, (0; +1), the event dummy variable takes on the value of 1 on the day of actual verified emissions data publication as well as the following day. For the longer window, (-1; +3), the event is defined as the time period from the day preceding the official data release to the third day (including) after the report publication.

The standard assumptions of the SUR model require the residuals to be independently and identically distributed over time for a specific company. Unlike the strict assumptions of classical OLS analysis, the residuals are allowed to be contemporaneously correlated ($E[\varepsilon_{it}\varepsilon_{jt}] \neq 0$) and to have different variances across equations ($E[\varepsilon_{it}^2] = \sigma_i^2 \neq E[\varepsilon_{jt}^2] = \sigma_j^2$) (Wooldridge, 2002). In his work on the SUR methodology, Zellner (1962) uses the Wald test for inference testing. Therefore, the significance of the abnormal return estimates for a given event a=1, ..., A is assessed against the null hypothesis that $\gamma_{1,a} = \gamma_{2,a} = \cdots = \gamma_{N,a} = 0$ for firms i = 1, 2, …, N. Average abnormal return (AAR) for verification event a (a = 1,…, A) is calculated as the arithmetic mean of firm-specific abnormal returns for that event:

$$AAR^{(a)} = \frac{\sum_{i=1}^{N} \gamma_{i,a}}{N} \tag{3}$$

With regards to the selection of regressors for the SUR model, I follow Galema et al. (2008) in my decision not to use a Fama-French-Carhart model. The authors demonstrate that in the context of a corporate social responsibility (CSR) event study such a model is inappropriate as it relies on risk premia which are directly affected by the level of CSR. Galema et al. (2008) document a trade-off between the financial and socially responsible investment (SRI) performance of a company, partly captured by the book-to-market ratio.

The authors report that socially responsible firms tend to be more growth-oriented than their competitors, which accordingly affects their returns. With carbon emissions representing an aspect of a firm's environmental performance, to avoid any potential growth biases in case some firms use their carbon performance as a part of a SRI strategy in addition to ETS compliance, I decide against using the Fama-French model. As a robustness check, in Section 4.6 of this chapter Equations 1 and 2 are re-run with both firm size and value premia added as explanatory variables.

4.4.2. Sources of abnormal returns

Having estimated abnormal returns through the SUR framework discussed above, I attempt to identify their sources. Panel data analysis allows me to capture the heterogeneity of firms with regards to the number of regulated installations they manage, their endowment of free EUAs and their actual emission levels. In order to link these firm-specific features to the presence of abnormal returns on the event days, I estimate the following models:

$$AR_{i,a} = \alpha + \beta_1 Allocated_{i,a} + \beta_2 Installations_{i,a} + \beta_3 MktCap_{i,a} + \beta_4 \frac{D}{E}_{i,a} + \eta + e_{i,a} \quad (4)$$

$$AR_{i,a} = \alpha + \beta_1 Verified_{i,a} + \beta_2 Installations_{i,a} + \beta_3 MktCap_{i,a} + \beta_4 \frac{D}{E}_{i,a} + \eta + e_{i,a} \quad (5)$$

$$AR_{i,a} = \alpha + \beta_1 (Allocated - Verified)_{i,a} + \beta_2 Installations_{i,a} + \beta_3 MktCap_{i,a} + \beta_4 \frac{D}{E}_{i,a} + \eta + e_{i,a} \quad (6)$$

$$AR_{i,a} = \alpha + \beta_1 \frac{Allocated}{Verified}_{i,a} + \beta_2 Installations_{i,a} + \beta_3 MktCap_{i,a} + \beta_4 \frac{D}{E}_{i,a} + \eta + e_{i,a} \quad (7)$$

where $AR_{i,a}$ is the abnormal return estimate ($\gamma_{i,a}$) for company i (i = 1,…, N) during verification event a (a = 1,…, A);

Allocated and *Verified* refers to the amount of freely allocated and actual emissions published for company i (i = 1,…, N) during event a (a = 1,…, A);

Installations refers to the number of covered installations a company is responsible for;

MktCap and *D/E* are, respectively, the market capitalization and debt-to-equity ratio of company i;

η refers to industry, country and time effects.

Large well-known companies tend to attract more investor interest and media coverage (Hamilton, 1995; Khanna et al., 1998). For instance, a "Dirty Thirty" index has been created to name and shame Europe's biggest polluters in terms of carbon emissions intensity. Firm size is accounted for by including the natural logarithm of market capitalization as a control variable. To control for the possible impact of industrial affiliation, I include industry dummy variables in the panel analysis. There are fundamental differences between the European member states covered by the ETS across several dimensions - emission reduction targets under the scheme, the energy intensity of GDP and the carbon intensity of energy (Zachmann and von Hirschhausen, 2008; Sinclair, 2011). The heterogeneity across countries is accounted for by including a dummy variable to represent the two countries. Similar to Khanna et al. (1998), I control for the riskiness of the individual firms by using the Debt-to-Equity ratio as an independent variable. A detailed description of the variables can be found in Table 4.1 in Section 4.5.4.

There are several potential problems with the error terms of Equations 4 to 7. The errors of firms at any given time may be correlated, for example, if the firms belong to the same industry. The possibility of spatial dependence between a firm's error terms cannot be ignored either. It is very likely that a firm's balance between actual and verified EUAs in one year affects the balance in the following year, i.e. the residual for a firm i during event

a is likely to be correlated with the residual for the same firm during event $a+1$. Spatial dependence in the error terms may arise because firm-specific characteristics tend to be interdependent over time. For example, the emissions intensity of the firm's operations remains fairly constant over time. To ensure the validity of the statistical inferences, robust standard errors adjusted for the clustering of individual firms are used. As an additional check, I perform Driscoll-Kraay (1998) adjustments to the standard errors and re-estimate the associated p-values. The method requires the estimation of a pooled OLS and adjusts the nonparametric time series covariance matrix estimator. Thus, "a Newey-West type correction to the sequence of cross sectional averages of the moment conditions" is applied (Hoechle, 2007).

4.4.3. ENVIRONMENTAL EFFECTIVENESS OF THE EU ETS

To test Hypothesis 5, a logistic regression is employed whereby the change in emissions intensity is modelled as a function of abnormal returns on the prior year's report publication. The estimated model takes on the following form:

$$\Delta\, Intensity_{i,a} = \alpha + \beta\, AR_{i,a-1} + \eta + e_{i,a} \qquad (8)$$

where Δ *Intensity* is the change in intensity measured over the period between verification events a-1 and a. It is coded as a binary variable, taking on the value of 1 for intensity reductions and 0 for intensity increases;

$AR_{i,a-1}$ is the abnormal return estimate for firm i (i = 1,…, N) during event $a-1$ (a = 2,…, A);

η denotes industry, country and time effects.A statistically significant negative regression coefficient of the abnormal returns variable will suggest that companies which experience a negative market response following the release of their emissions tend to improve their carbon performance in the following year by reducing their emissions intensity.

To test Hypothesis 6, a pooled OLS in the following form is estimated:

$$AR_{i,a} = \alpha + \beta\Delta\, Intensity_{i,a} + \eta + e_{i,t} \qquad (9)$$

where Δ *Intensity* is the actual percentage change in intensity measured over the period between verification events a-1 and a. $AR_{i,a}$ is the abnormal return estimate for company i (i = 1,…, N) during event a (a = 1,…, A).

A statistically significant regression coefficient of the Δ *Intensity* variable suggests that the market response on the event day is conditioned on the change in corporate carbon performance.

A potential endogeneity issue needs to be acknowledged with regard to Equations 8 and 9 where event returns and emissions intensity are used interchangeably as independent and explanatory variables. Because Equation 9 uses a lagged estimate of emissions intensity and relies on a different estimation methodology (pooled OLS versus the logistic regression used in Equation 8), endogeneity is not explicitly accounted for in the regressions. Further work is certainly needed in order to establish the direction of causation between carbon performance and market reactions, and future research may explore this issue by employing co-integration models.

4.5. DATA

4.5.1. THE COMMUNITY INDEPENDENT TRANSACTION LOG (CITL)

Public access to government information about firm-specific environmental performance can empower market participants, spur public debate and provoke investor action (Jobe, 1999). As discussed in Section 3.2.1.2 of Chapter 3, under the EU ETS there is a mandatory requirement for covered installations to provide information about their allocated and actual emissions for every calendar year. The community system of registries which contains all this information was set up to handle the purely administrative aspects of the ETS and to "ensure that the issue, transfer and cancellation of allowances does not involve irregularities and that transactions are compatible with the obligations resulting from the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto protocol"[31]. Each Member State has a national registry which contains information on all of the regulated installations, their allocated allowances and actual emissions as well as the units surrendered for compliance purposes. All of the national registries are connected to a central European registry, the EC-run Community Independent Transaction Log (CITL). Unlike voluntarily disclosed data, all the information which firms provide to the EC about their actual carbon emissions throughout the year has to be checked by an independent verifier. Verified emissions data is posted on the CITL website in April/May of each year. Thus, the registry provides the ideal setting to examine the willingness of financial markets to incorporate carbon performance in the valuation of covered companies.

Several shortcomings of the data available on the CITL database have been identified in prior literature. First, ex-post corrections to the information from the national registries may not be reflected in the CITL. Second, not all relevant information is included in the

[31] Commission Regulation (EC) No 2216/2004 of 21 December 2004 for a standardized and secured system of registries pursuant to Directive 2003/87/EC of the European Parliament and of the Council and Decision No 280/2004/EC of the European Parliament and of the Council

database i.e. Phase I lacked information on the EUA reserves created for new industry entrants[32]; there is still no clarity about the exact nature of the covered installation's activity (Trotignon and Delbosc, 2008). A key piece of information missing from the registry is the fines, if any, and their amounts, imposed on those companies which have failed to report their verified emissions on time and those which have failed to supply enough allowances to cover their actual emissions. The most serious flaw in the CITL database remains, however, the format of the presented data. Within the EU ETS framework, carbon reporting is carried out at installation-level rather than at firm-level and the registry contains virtually no data on the identity of the parent company. This considerably reduces the transparency of the data and undermines the ability of investors to easily and quickly assess company performance.

4.5.2. Sample construction

All installations whose carbon emissions are covered by the ETS are grouped together by parent company. In order to determine the ultimate ownership of the installation, all facilities were manually checked against the Nexis database (including the Directory of Corporate Affiliations and the Extel cards database). Firm data is constructed by accounting for installations in which the company has a substantial interest i.e. it owns 50% or more of the installation. Thus, JVs and minority interests in installations are removed from the analysis. When a change in ownership is identified, a simple arithmetic rule is applied to calculate the amount of allocated EUAs or the number of installations covered by a company. For example, if RWE acquires an installation via M&A activity in February

[32] New Entrants Reserves (NERs) for Phase I were not incorporated in the CITL data, leading to a biased estimate of a given installation's compliance. This left market participants unable to assess the net position of each installation, as deficits would appear larger without the adjustment for NERs (Trotignon and Delbosc, 2008)

of a given year, the amount of allocated EUAs attributed to RWE from that installation alone is estimated as 10/12*(annual allocated EUAs for the installation). Similarly, RWE will be considered to have an additional 0.83 (rather than 1) installation during the year of acquisition. It is also worth noting that not all of the installations which a company is responsible for are located in the company's home country. For instance, Diageo has distilleries covered by the EU ETS which are located in Ireland. For the purposes of this chapter, all covered installations which a company owns are counted regardless of their geographical location. Similarly, allocated and verified EUAs are added up across all installations for which a company is responsible.

Following an in-depth analysis of the CITL data, installations were linked to 50 publicly - traded companies in the United Kingdom[33] and 46 in Germany. The initial dataset is limited to firms meeting the following criteria:

1. Listing requirements - to be included in the analysis, a firm must be publicly traded throughout the entire time period under investigation, January 2006 – November 2011. As a result, 8 companies are discarded – 5 from the German subsample and 3 from the British subsample.
2. Liquidity requirements – to minimize biases arising from thin trading, I remove companies in which no trading takes place more than 40% of the time, excluding official exchange holidays. 10 additional firms are eliminated – 5 in each of the two countries.

[33] Royal Dutch Shell is considered a UK company as their country of incorporation is the United Kingdom and a substantial part of their activities take place there

In addition, another UK company is removed from the dataset as it files for receivership and stops trading actively in 2009. The final sample contains 41 British and 36 German publicly-traded companies. The full list of included companies and their industrial affiliations can be found in Appendix 4A. For each of the verification events, a smaller sample is used as confounding announcements are controlled for in the 5 days surrounding the emissions data release. Confounding events are defined as earnings announcements and publications of either interim financial statements or annual reports.

4.5.3. Event days

The events analysed in this study take place on the following dates:

- 25 April 2006 (VER2005a) – information is published by EU Member States before the officially scheduled release of data by the European Commission. France, the Netherlands, the Czech Republic, Estonia and Spain all leaked information on the level of verified emissions for the calendar year 2005.
- 15 May 2006 (VER2005b) – official release of data by the EC. The UK and Germany release information on the levels of verified emissions for the first time.
- 2 April 2007 (VER2006) – data on verified emissions in 2006 is published by the EC
- 2 April 2008 (VER2007) – data on verified emissions in 2007 is published by the EC
- 1 April 2009 (VER2008) – data on verified emissions in 2008 is published by the EC
- 1 April 2010 (VER2009) – data on verified emissions in 2009 is published by the EC
- 1 April 2011 (VER2010) – data on verified emissions in 2010 is published by the EC

4.5.4. Return-generating models for German and British companies

As discussed in Section 4.4.1, the returns of the sample companies are modelled as a function of the market portfolio, carbon, electricity and the foreign exchange rate. In their work on multi-country event study methods, Campbell et al. (2009) demonstrate that market-adjusted and market-model methodologies with local market indices are sufficient to produce well-specified inference tests on the significance of the market response on the event day. Following Campbell et al. (2009), I use the FTSE All Share Index as a proxy for the UK market and the DAX index as a proxy for the German market.

Electricity is selected as a priced risk factor because both energy producers and consumers are sensitive to changes in electricity prices, albeit in a different fashion and to a different extent. The choice of electricity price series is challenging because there is no common market for electricity in the EU. The spot price of the Phelix Month Base contracts traded on the European Energy Exchange is selected as a proxy for German electricity prices (following Veith et al., 2009; Oberndorfer, 2009) and the spot price of contracts traded on the Amsterdam Power Exchange UK (APX UK) as representative of the UK power prices[34].

To ensure that changes in firm value on the event day are not driven by carbon price movements or currency fluctuations, I add the continuously compounded returns of EUA futures contracts and the returns on the spot exchange rate as independent variables. The exchange rate reflects relative movements between the Pound and the Euro, whereby a positive return signals an appreciation of the Pound/devaluation of the Euro. Detailed description of all the variables and the sources of data are presented in Table 4.1.

[34] APX-ENDEX acquired UK Power exchange, one of the three main power platforms in the United Kingdom, in 2000 and renames it to APX Power UK. Given its size, the spot electricity prices on the APX UK are considered as representative of UK prices. <www.apxendex.com>

Table 4.1 Description of the variables and data sources

Variable	**Description and Data source**
Electricity	Electricity prices from the Amsterdam Power Exchange are selected as representative for the UK market. Spot prices are quoted in Pounds per Megawatt hour (Mwh). Electricity prices from the European Energy Exchange are used for the German market. Spot prices of the Phelix Month Base contracts are denominated in Euro per Mwh. Source: Datastream
Local Market Index	The FTSE All Share index is used as a proxy for the market potfolio in the United Kingdom. DAX30 is used as a local market index in Germany. Source: Datastream
EUA	Nearest to expiration December futures contracts traded on the European Climate Exchange are used to estimate returns on carbon allowances. Source: The ICE official website, www.theice.com
FOREX	The Thomson Reuters daily spot exchange rate of Pound Sterling to Euro is used. Source: Datastream
Stock prices	Stock prices adjusted for capital events (P) like stock splits are used. Source: Datastream
Market Capitalization ("MktCap")	Market capitalization (WC08001) is calculated as the market price at fiscal year-end multiplied by the amount of common shares outstanding. It is measured in thousands. Source: Worldscope Database in Datastream
Installations	The number of installations which a company is responsible for under the EU ETS. Only installations in which a company has a controlling interest are considered.
Verified EUAs ("Verified")	Actual carbon emissions over the year are measured in millions.
Allocated EUAs ("Allocated")	Allocated carbon allowances for the year are measured in millions.
Net Position	The difference between allocated EUAs and actual emissions over a given calendar year. The net position is measured in millions of allowances.
Allocation Factor	The ratio of freely allocated EUAs to the actual emissions over a given calendar year.
Debt -to-Common Equity ("D/E")	(Long Term Debt + Short Term Debt & Current Portion of Long Term Debt) / Common Equity * 100 Source: Worldscope Database
Industry	The variable "Industry" represents a firm's industrial affiliation. It is assessed using Datastream Level 2 industry classification, which is based on the Industry Classification Benchmark (ICB) jointly established by the FTSE and Dow Jones. Level 2 industry levels divide the total market into 10 industries and cover all sectors within each group in each country. Source: Datastream Global Equity Indices
Emissions Intensity	Actual carbon emissions divided by the Net Revenue for a given year.

4.6. EMPIRICAL RESULTS

The descriptive statistics of the companies in the dataset are summarised in Table 4.2. The companies vary widely in size and riskiness (as evidenced by the large standard deviations of market capitalization and the debt-to-equity ratio). Over the 5-year period from 2006 until 2010, the average firm was over-allocated emissions certificates. The excess of freely allocated EUAs to the actual needs of the business ranged from an average of 17% in 2006 to 46% in 2009. The other point worth noting is the tendency towards a decrease in the average emissions intensity of companies over time. It remains unclear whether the observed intensity reductions are the result of compliance with the EU ETS. The return time series of all dependent and independent variables used in the analysis are tested for unit roots with an Augmented Dickey-Fuller test.

Table 4.2 Firm characteristics
This table presents the descriptive statistics of the firms included in the sample over the period January 2006 – December 2010. The reported values are the arithmetic means of each indicator for any given year. Standard deviations are presented in italics.

	2006	**2007**	**2008**	**2009**	**2010**
Capitalization (in mln €)	21500	24400	16000	17800	20600
	33000	*35200*	*25700*	*26700*	*29700*
Debt-to-Equity	1.23	1.16	1.22	2.67	1.13
	2.21	*2.03*	*1.75*	*11.13*	*2.07*
EBITDA (in mln €)	4128	4182	3583	3138	3945
	7332	*6950*	*5875*	*5055*	*6096*
Allocated EUAs (in 000)	5481	5593	3862	3872	3952
	19569	*19745*	*12153*	*12129*	*12336*
Verified emissions (in 000)	5973	6119	5260	4692	5000
	21780	*22147*	*19980*	*17607*	*18439*
Allocation factor	1.17	1.33	1.19	1.46	1.37
	0.50	*0.78*	*0.56*	*1.12*	*0.83*
Installations	9	9	9	9	9
	17	*17*	*17*	*18*	*17*
Emissions intensity	0.53	0.52	0.35	0.37	0.37
	2.09	*2.24*	*1.52*	*1.61*	*1.63*

As seen from Table 4.3 below, the two industries with the biggest representation in the sample are Consumer Goods and Industrials (accounting for 25% and 23% of all firms, respectively). However, these industries do not play a critical role for the ETS – they receive small amounts of free carbon certificates and jointly emit less than 5% of all the carbon released by the firms in the dataset. Utilities, on the other hand, are granted 60% (71%) of all free carbon allowances in Phase II (I) of the scheme and are responsible for 72% (75%) of the actual emissions for the respective period. As reported by the carbon pressure group Sandbag, RWE[35] and E.on have been the two companies most short of permits in the ETS, and together they had to abate internally or purchase allowances for more equivalent emissions reductions than the net reductions of the scheme as a whole (Sandbag, 2010).

The second largest emitter is the Oil and Gas industry, represented by only 5 firms, all of which are located in the UK. The allocation of EUAs in the sample of firms appears to be representative of the population of firms, public and private, covered by the EU ETS. The number of firms from each industry represented in the sample and their allocated EUAs is in line with what Trotignon and Delbosc (2008) call "allowance concentration" in the market. In their analysis of the CITL data over the first trading period of the cap-and-trade programme, they find that the largest company in terms of freely allocated EUAs received 6% of total allowances; the first 10 companies possessed a third of all the allowances and the first 100 held about 75% of all available allowances (Trotignon and Delbosc, 2008). Thus, the EU ETS appears to be dominated by the actions of a few large power companies.

[35] According to the Dirty Thirty ranking of Europe's dirtiest power stations, 4 out of the top 10 biggest emitters in 2005 were owned by RWE. The company was responsible for 4 out of the 7 dirtiest plants in both 2008 and 2009.

Table 4.3 Distribution of sample companies across industries
This table reports the distribution of publicly-traded British and German companies with installations covered by the EU ETS across industries. Emissions certificates granted for free to any given industry over the different trading periods are calculated as the sum of all EUAs allocated to companies in that industry. Allocated allowances for each industry are presented as a percentage of all allowances received by the firms in the dataset. Actual emissions for each industry are estimated and reported in a similar fashion.

Industry	GER	UK	Industry as % of total	Allocated EUAs as % of total sample		Verified CO2 as % of total sample	
Consumer goods	10	9	24.68%	Phase I:	1.08%	Phase I:	0.92%
				Phase II:	1.46%	Phase II:	1.07%
Industrials	10	8	23.38%	Phase I:	4.76%	Phase I:	3.81%
				Phase II:	6.66%	Phase II:	3.84%
Basic materials	7	6	16.88%	Phase I:	3.76%	Phase I:	3.34%
				Phase II:	6.85%	Phase II:	4.34%
Utilities	4	7	14.29%	Phase I:	71.61%	Phase I:	75.84%
				Phase II:	60.33%	Phase II:	72.00%
Oil & Gas	0	5	6.49%	Phase I:	18.32%	Phase I:	15.76%
				Phase II:	24.10%	Phase II:	18.42%
Healthcare	3	3	7.79%	Phase I:	0.41%	Phase I:	0.29%
				Phase II:	0.53%	Phase II:	0.28%
Technology	2	1	3.90%	Phase I:	0.05%	Phase I:	0.03%
				Phase II:	0.04%	Phase II:	0.03%
Tele-communications	0	1	1.30%	Phase I:	0.01%	Phase I:	0.01%
				Phase II:	0.01%	Phase II:	0.01%
Financials	0	1	1.30%	Phase I:	0.00%	Phase I:	0.00%
				Phase II:	0.02%	Phase II:	0.01%

4.6.1. Investor reactions to unanticipated changes in the levels of actual emissions

All individual abnormal returns estimated from Equations 1 and 2 are reported in Appendix 4B. The significance of the regression coefficients is confirmed with a Wald test. For brevity, the regression output for each company is not reported here. Some of the results, however, are worth noting. In line with Oberndorfer (2009), Veith et al. (2009) and Bushnell et al. (2009) a positive association (significant for the majority of firms) is found between the returns of electricity producers and emission allowances. The positive slope coefficient of the carbon variable in explaining returns of companies in the Utilities and Oil and Gas industries implies that EUAs are largely seen as an asset by these firms. On the other hand, carbon allowances are seen as a production cost by firms in the Basic materials, Industrials and Consumer goods industries as evidenced by the negative coefficient of carbon.

Because both the UK and Germany did not release their actual emissions until May 15th, 2006, the majority of firms did not react to the leaked information by other EU Member States in late April 2006. Therefore, the "Ver2005a" event is discarded from the panel data and the analysis focuses on abnormal returns generated at the official release date only (i.e. "Ver2005b"). In the whole sample only 4 (7) firms experience significant abnormal returns in 2005 over the short (long) event window; only 1(0) in 2006; 2 (4) in 2007; 23 (24) in 2008; none in 2009; and lastly, just 1 (0) in 2010. Average abnormal returns (AARs) are calculated separately for companies which experience good and bad news as specified in Hypothesis 1. The results are reported in Table 4.4.

Contrary to expectations, no statistically significant market reactions are associated with the compliance events, except for the 2008 verified data release. The prevailing lack of significant price effects implies that the annual compliance event does not lead investors to re-assess the future cash flows associated with the company by making an allowance for greater/lower environmental compliance costs and/or windfall profits than previously anticipated. One alternative explanation is that the return-generating models for German and British companies would be flawed and abnormal returns may be understated. In Section 4.7 of this chapter, I confirm that the AAR estimates are robust to the additions of alternative priced risk factors. Another explanation could be information leakage. However, because informal release of emissions data prior to the official disclosure for all 77 companies examined in this chapter seems unlikely, I tend to favour the view that

Table 4.4 Investor reactions to unanticipated changes in actual emissions relative to expectations

Average abnormal returns (AAR) are calculated as the mean market reactions to a specific verification event across firms. AARs are estimates over both (0; +1) and (-1; +3) event windows. The Wald test is used to establish the significance of the abnormal return estimates. * denotes significance at the 1% level.

	Actual < Expected emissions (Good news)			**Actual > Expected emissions (Bad news)**			**H_0: $AAR_{good\ news}$ > $AAR_{bad\ news}$**	
	AAR (o; +1)	**AAR (-1; +3)**	**Firms**	**AAR (o; +1)**	**AAR (-1; +3)**	**Firms**	**AAR (o; +1)**	**AAR (-1; +3)**
VER 2005b	-0.247%	-0.334%	38	0.049%	-0.130%	26	-0.289%	-0.204%
							(0.8634)	(0.8709)
VER 2006	0.196%	0.059%	58	-0.022%	0.015%	6	0.218%	0.044%
							(0.2425)	(0.4216)
VER 2007	-0.079%	-0.094%	51	-0.307%	-0.168%	13	0.228%	0.074
							(0.2336)	(0.3599)
VER 2008	-0.123% *	0.192% *	53	0.687% *	1.067% *	18	-0.81%	-0.878%
							(0.9361)	(0.9776)
VER 2009	0.023%	-0.028%	45	-0.042%	0.083%	27	0.065%	-0.111%
							(0.3256)	(0.8370)
VER 2010	0.226%	0.062%	44	0.628%	0.226%	28	-0.402%	-0.164%
							(0.9380)	(0.9109)

investors simply don't consider firm-specific carbon performance as value-relevant at present.

Lack of investor interest in the carbon performance of companies would also explain why no statistically significant reaction was observed at the first compliance event which disclosed the verified emissions for 2005. Prior to the launch of the EU ETS, carbon emissions data was not publicly available and the first EC report arguably contained new information. It revealed to investors the firms' actual carbon performance and their ability to achieve the required targets. All subsequent reports will contain less incremental information as there is now a benchmark against which future emissions performance can be forecasted. The lack of market reaction following the 2005 emissions data publication may be the result of the inefficiency of the market in its early stages, high levels of initial uncertainty surrounding the future of scheme, or inability of market participants to assess the implications of the ETS for a given company.

There is also the possibility that the adjustments needed due to the discrepancy between actual and expected emissions are too small in monetary terms to meaningfully affect valuations. With the low carbon prices, the impact on profits (costs) arising from excess (shortage) of allowances may be negligible compared to firm size to induce a meaningful revaluation of the firm's market value and its future profitability. For example, according to the model of expectations formation used here National Grid had an unanticipated excess of 656,539 carbon allowances in 2009. The average price of the futures with December 2009 expiration during the year was approximately €13.38 which would translate into a pre-tax profit of 656, 539 x €13.38 = € 8,784,492 if the allowances were sold in the open market. With a total market capitalization of £44,330 mln at the 2009 fiscal year end, the unexpected after-tax profit from unused emission certificates may not be material enough to bring a significant market reaction. As noted by Veith et al. (2009) though: “investors perceive a trade in emission certificates as an additional factor in valuing the regulated firms only as long as it seriously impacts earnings: an ETS with certificate prices ranging marginally above zero …guarantees for inexpensive business-as-usual scenarios”. This reasoning is also in line with Grubb et al. (2009) who argue that carbon prices are not a critical factor affecting profitability. The authors state that “cost differentials due to labour and other input costs for most sectors far outweigh any international differences in the cost of carbon” and “the cost uncertainty induced by emissions trading is also less than that, for example, due to energy cost and exchange-rate fluctuation” (Grubb et al., 2009: p. 20).

The release of the 2008 verified emissions data is the only event associated with a statistically significant price response among covered companies regardless of the event window over which abnormal returns are estimated. 2008 was the first year of Phase II and the amounts of allocated emissions to covered companies were substantially reduced. Uncertainty about the new EUA demand-supply balance for companies might have led investors to respond to the emissions data publication. Average abnormal returns of 0.69% (1.07% over the longer event window) are found for companies which experience bad news and -0.12% (0.19%) for companies which experience good news. The signs are contrary to those expected under Hypothesis 1, suggesting that the investor reactions on the event day are not likely to be conditioned upon the exact amount of over (under)-emitting relative to expectations.

In addition, a one-tailed t-test is performed to compare the average abnormal return estimates for the subsample of firms which emit less than anticipated and those which emit more than anticipated. The results of the test, along with the differences in average abnormal returns, are reported in the last two columns of Table 4.4. For all of the verification events, the null hypothesis that companies which experience good news have a higher abnormal return than those which experience bad news is rejected. This confirms that investor reactions on the event day do not depend on the amount of unanticipated emissions relative to expectations.

4.6.2. Investor reactions to unanticipated changes in the net EUA positions

Table 4.5 below reports the results of Hypothesis 2 whereby investors react to news about unanticipated changes in the firms' net positions with respect to emission allowances. As in Table 4.4, only AARs following the release of the 2008 report are found to be statistically different from zero. The signs are better aligned with expectations – positive abnormal returns are associated with companies which find themselves long on EUAs despite expectations of being short (0.35% and 1.11% for the short and long event windows, respectively) and negative (-1.51% for the short window) for companies which contrary to expectations end up net short. Over the long window, however, AARs for companies which experience bad news is positive at 0.57%. The "No news" subcategory of firms also experienced a positive price reaction to the report publication, contrary to the expected lack of abnormal returns.

The investor behaviour described in Hypothesis 2 seems to describe better than Hypothesis 1 the observed stock price changes in covered companies, at least for the 2008 verification event which is the only one that resulted in abnormal returns distinguishable from zero. In addition, the one-tailed test comparing the average abnormal returns for companies which experience good news and those which experience bad news confirms that the former had higher abnormal returns than the latter during the 2006 (for both event windows used in the analysis) and during the 2008 (only for the short event window) verified emissions data releases. Investors appear to react to unexpected changes in the net EUA positions rather than unexpected levels of emissions. The net position may be interpreted as an indicator of the firm's carbon practices, a signal for future compliance liabilities or benefits. Discrepancies between the actual and expected levels of emissions may be triggered by short-term changes in the firm's level of production and may not be seen as a reliable proxy of future carbon performance.

It should be noted that for the 2008 event, abnormal returns over the longer event window for all categories of companies are larger compared to the (0; +1) event window. If the market is efficient, abnormal returns over the longer event window should be close to zero, as the novelty of the carbon information gets gradually incorporated into stock prices. Larger abnormal returns over the (-1; +3) event window imply that market participants were slow to respond to the news about the carbon performance of ETS-covered companies. The reported delay in integrating carbon performance data into firm valuations might be caused by the time it takes investors to process the report released by the EC and to transform the installation-level data into meaningful company-level information. A policy change whereby carbon reporting is carried out on a firm-basis rather than per

Table 4.5 Investor reactions to unanticipated changes in the net EUA positions
Net position is defined as the difference between actual and expected carbon emissions levels. Average abnormal returns (AAR) are calculated as the mean market reactions to a specific verification event across firms. AARs are estimates over both (0; +1) and (-1; +3) event windows. The Wald test is used to establish the significance of the abnormal return estimates. ***, **, * denote significance at the 10%, 5% and 1% levels, respectively.

	Good news			No news			Bad news			H_0: $AAR_{good\ news}$ $>AAR_{bad\ news}$	
	AAR (0;+ 1)	**AAR (-1;+ 3)**	**Firms**	**AAR (0;+ 1)**	**AAR (-1;+ 3)**	**Firms**	**AAR (0;+ 1)**	**AAR (-1;+ 3)**	**Firms**	**AAR (0;+ 1)**	**AAR (-1;+ 3)**
VER 2006	0.016%	-0.076%	17	0.249%	0.114%	46	-0.457%	-0.461%	1	0.473%*	0.385%*
										(0.0058)	(0.0069)
VER 2007	-0.252%	-0.123%	16	-0.071%	-0.100%	46	-0.059%	-0.160%	1	-0.193%	0.037%
										(0.7579)	(0.4029)
VER 2008	0.347% **	1.109% **	12	0.189% *	0.282% *	48	-1.505% ***	0.568% ***	6	1.852%**	0.541%
										(0.0341)	(0.3244)
VER 2009	0.014%	-0.079%	5	-0.026%	0.019%	64	0.498%	0.055%	3	-0.484%	-0.134%
										(0.8675)	(0.6390)
VER 2010	0.173%	0.008%	9	0.351%	0.160%	59	1.317%	-0.111%	4	-1.144%	-0.152%
										(0.9724)	(0.3587)

installation might facilitate the assimilation of information and improve the speed at which market participants digest the information.

4.6.3. HIGH AND LOW CARBON-INTENSIVE INDUSTRIES

To test whether carbon disclosures are more important for high carbon-intensive industries than for low carbon-intensive industries, I compare the magnitude of their market reactions following ETS report publications. The strength of the response is measured as the absolute size of the abnormal return estimate. Carbon intensity is calculated as the ratio of verified emissions for the year divided by the net sales for the year. The 20 companies with the highest and lowest intensities are identified for each of the compliance events. In a paired t-test, the difference between the AARs experienced by high and low intensity companies is compared.

Table 4.6 A comparison of the magnitude of price response between the two portfolios formed on emissions intensity
At every annual compliance, 2 portfolios are formed each made up of 20 companies on the basis of emissions intensity – "high intensity" and "low intensity". Emissions intensity is estimated as the ratio of verified emissions for a given calendar year divided by net sales over the period. For each portfolio, the table shows average absolute abnormal returns across verification events for the (0; 1) and (-1; +3) event windows. A one-tailed paired t-test is carried out to compare the average absolute abnormal returns over the 20 companies with highest CO_2 emissions intensity and the 20 with the lowest. Ho: mean(diff)=0, Ha = mean(diff)>0. T-statistics are reported in parentheses. ***, **, * denote significance at the 10%, 5% and 1% level.

	High Intensity		Low Intensity		Difference	
	AR(0; +1)	**AR(-1; +3)**	**AR(0; +1)**	**AR(-1; +3)**	**AR(0; +1)**	**AR(-1; +3)**
2005	1.1234%	0.64%	0.6093%	0.4501%	0.5141%*	0.1898%
					(2.5642)	(1.0715)
2006	0.6867%	0.4622%	0.539%	0.4025%	0.1477%	0.0597%
					(0.853)	(0.9681)
2007	0.6165%	0.3866%	1.0413%	0.6502%	-0.4247%	-0.2636%
					(-1.6613)	(-1.7166)
2008	1.4821%	1.3984%	1.2621%	1.0466%	0.22%	0.3518%
					(0.7781)	(0.8307)
2009	0.4276%	0.386%	0.4539%	0.3473%	-0.0264%	0.0387%
					(-0.1958)	(0.4909)
2010	0.9751%	0.4245%	0.5945%	0.3286%	0.3806%***	0.0959%
					(1.411)	(1.0193)

As seen in Table 4.6, with the exception of 2007, the average absolute market reaction for firms with high intensity was larger in magnitude than for low-intensity firms. Although the difference between high and low intensity firms is positive, it is significant only for the 2005 and 2010 verification events when abnormal returns are calculated over the (0; +1) event window. These findings lend some credence to Hypothesis 3 that the ETS reports are more important for high carbon intensity companies relative to low carbon intensity ones.

4.6.4. Determinants of observed market responses

This section of the analysis attempts to identify the factors which drive observed market reactions on the event days. A random effects model is chosen over a fixed effects one because it allows for analysis of time-invariant determinants of abnormal returns such as country, industry affiliation and the number of installations which a company is responsible for under the EU ETS. Since these characteristics are constant over time, they cannot lead to changes in the firm-specific abnormal return estimates. In a fixed effects model these time-invariant independent variables are absorbed by the intercept. A Hausman test is used to empirically confirm the use of a random effects model over a fixed effects one.

Table 4.7 presents the results of the panel data analysis where industry effects are controlled for. Four alternative models are estimated with the following determinants of market reactions: allocated EUAs, actual emissions, net EUA position, and the allocation factor. Overall model evaluation is based on a Wald test and the chi-square statistics as well as their corresponding p-values are reported for each model. Driscoll-Kraay (1998) standard errors are estimated but not reported because they lead to the same qualitative conclusions about the significance of the coefficients.

As seen in Table 4.7, allocated EUAs, verified emissions and the net EUA position show up with their hypothesized signs. In magnitude, however, the coefficient of allocated EUAs and actual emissions are so small that a Wald test rejects their statistical significance for both event windows used in this study. The net EUA position gains significance at the 10% only for the longer (-1; +3) event window. The regression slope is virtually equal to zero and implies that if a firm's excess EUAs go up by 1 million, abnormal returns will go up by only 0.01%. The allocation factor, instead of having the expected positive sign, enters the regression output with a negative sign. It is, however, insignificantly different from zero. The insignificance of the allocated and verified emissions as determinants of abnormal returns suggests that, at face value, carbon performance doesn't really matter.

No evidence is found to support the conclusions of Hamilton (1995) that large companies

attract more investor attention and experience greater market reactions. Capitalization remains insignificant, regardless of what event window is used to estimate abnormal returns. The debt-to-equity is found to be a statistically significant determinant, whereby riskier firms (i.e. higher debt-to-equity ratio firms) experience lower abnormal returns, holding everything else constant. The only industry affiliation which appears to have a significant impact on the market reaction is Oil and Gas, where companies in this industry experience lower abnormal returns. The results for the Telecommunications industry, while seemingly significant over the (-1; +3) event window, need to be interpreted carefully because the industry is represented by a single company, the British enterprise BT Plc. The number of installations which a company is responsible for remains insignificant.

In addition to the industry effects, country and time effects are also controlled for in Table 4.8. The goodness-of-fit of the model improves slightly as evidenced by the increase in the coefficient of determination from (5.33%-6%) for the industry effects model to (8.16%-11.16%) for the all-inclusive model. The results remain qualitatively identical as the findings reported in Table 4.7. The level of verified and allocated allowances remains insignificantly different from zero, albeit showing up in the regression output with the expected signs. The net position of the company remains significant over the longer event window. The allocation factor also gains significance at the 10% level over the (0; +1) event window. The number of firms which a firm is responsible for and the firm's country are irrelevant in explaining abnormal returns. The results in Table 4.8 suggest that once time effects are accounted for, the rest of the regressors lose significance. This might suggest that instead of company specific factors, the observed abnormal returns are driven by an unobserved factor, common to the entire carbon market.

Table 4.7 Determinants of observed market reactions (Industry effects)

This table reports the results of the following random effects model: $AR_{i,t} = \alpha + \beta_1 Carbon\ variable_{i,t} + \beta_2 Installations_{i,t} + \beta_3 MktCap_{i,t} + \beta_4 \frac{D}{E}_{i,t} + \eta + e_{i,t}$, where the four carbon variables which are examined are: Allocated EUAs (1), Verified emissions (2), Excess/Shortage of EUAs (3), Allocation ratio (4). η captures industry effects. A detailed description of all variables can be found in Table 4.1. The results of the Wald test for the joint insignificance of all explanatory variables are reported, along with the corresponding p-values. Robust standard errors are employed. ***, **, * denote significance at the 10%, 5% and 1% levels.

Panel A: Average abnormal returns are measured over the (0; +1) event window

	(1)	(2)	(3)	(4)
Allocated EUAs	0.00002			
Verified emissions		0.00000		
Excess/Shortage EUAs			0.00009	
Allocation factor				-0.00074
Installations	0.00002	0.00003	0.00005	0.00003
Capitalization	-0.00042	-0.00041	-0.00042	-0.00042
Debt-to-Equity	-0.00006***	-0.00006***	-0.00007***	-0.00006
Consumer goods	0.00171	0.00169	0.00163	0.00106
Industrials	-0.00092	-0.00088	-0.00096	-0.00154
Basic materials	0.00145	0.00147	0.00139	0.00088
Utilities	-0.00317	-0.00299	-0.00270	-0.00366
Oil & Gas	-0.00731***	-0.00723***	-0.00736***	-0.00781***
Healthcare	-0.00224	-0.00223	-0.00226	-0.00275
Technology	-0.00700	-0.00694	-0.00694	-0.00748
Telecommunications	0.00468	0.00468	0.00468	0.00384
Constant	0.00798	0.00779	0.00794	0.00959
Observations	407	407	407	407
R-squared	5.82%	5.78%	5.91%	6%
Wald Chi-squared (12df)	27.65	27.51	28.11	29.43
p-value	0.0062	0.0065	0.0053	0.0034

Panel B: Average abnormal returns are measured over the (-1; +3) event window

	(1)	(2)	(3)	(4)
Allocated EUAs	0.00000			
Verified emissions		-0.00001		
Excess/Shortage EUAs			0.00010***	
Allocation factor				-0.00051
Installations	0.00003	0.00004	0.00004	0.00002
Capitalization	-0.00030	-0.00029	-0.00031	-0.00031
Debt-to-Equity	-0.00011*	-0.00011*	-0.00011*	-0.00010*
Consumer goods	0.00104	0.00102	0.00098	0.00061
Industrials	0.00053	0.00054	0.00044	0.00007
Basic materials	0.00060	0.00060	0.00052	0.00020
Utilities	-0.00041	-0.00026	-0.00012	-0.00089
Oil & Gas	-0.00431**	-0.00429**	-0.00445**	-0.00471**
Healthcare	-0.00162	-0.00162	-0.00164	-0.00198
Technology	0.00424	0.00427	0.00422	0.00386
Telecommunications	0.00910**	0.00910**	0.00910**	0.00852**
Constant	0.00476	0.00468	0.00494	0.00603
Observations	407	407	407	407
R-squared	5.33%	5.37%	5.6%	5.53%
Wald Chi-squared (12df)	26.59	27.18	29.98	27.6
p-value	0.0089	0.0073	0.0028	0.0063

Table 4.8 Determinants of observed market reactions (Industry, country and time effects)

This table reports the results of the following random effects model: $AR_{i,t} = \alpha + \beta_1 Carbon\ variable_{i,t} + \beta_2 Installations_{i,t} + \beta_3 MktCap_{i,t} + \beta_4 \frac{D}{E}_{i,t} + \eta + e_{i,t}$, where the four carbon variables which are examined are: Allocated allowances (1), Verified emissions (2), Excess/Shortage of EUAs (3), Allocation ratio (4). η captures the industry, country and time effects. A detailed description for the remainder of variables can be found in Table 4.1. The results of the Wald test for the joint insignificance of all explanatory variables are reported, along with the corresponding p-values. Robust standard errors are employed. ***, **, * denote significance at the 10%, 5% and 1% levels.

Panel A: Average abnormal returns are measured over the (0; +1) event window

	(1)	(2)	(3)	(4)
Allocated EUAs	0.00003			
Verified emissions		0.00000		
Excess/Shortage EUAs			0.00011	
Allocation factor				-0.00083***
Installations	0.00002	0.00003	0.00005	0.00003
Capitalization	-0.00042	-0.00041	-0.00042	-0.00042
Debt-to-Equity	-0.00005	-0.00006	-0.00006	-0.00005
Consumer goods	0.00239	0.00233	0.00227	0.00168
Industrials	-0.00034	-0.00033	-0.00042	-0.00101
Basic materials	0.00211	0.00209	0.00201	0.00149
Utilities	-0.00237	-0.00217	-0.00179	-0.00291
Oil & Gas	-0.00628	-0.00620	-0.00633	-0.00684
Healthcare	-0.00159	-0.00162	-0.00163	-0.00215
Technology	-0.00683	-0.00681	-0.00682	-0.00735
Telecommunications	0.00548	0.00546	0.00550	0.00457
United Kingdom	-0.00047	-0.00052	-0.00056	-0.00045
2006	0.00322**	0.00326**	0.00326**	0.00327**
2007	0.00008	0.00011	0.00011	0.00025
2008	0.00202	0.00202	0.00213	0.00204
2009	0.00128	0.00127	0.00131	0.00150
2010	0.00510*	0.00510*	0.00517*	0.00525*
Constant	0.00558	0.00544	0.00557	0.00726
Observations	407	407	407	407
R-squared	8.19%	8.16%	8.33%	8.38%
Wald Chi-squared (18df)	36.17	36.4	37.79	38.02
p-value	0.0067	0.0063	0.0041	0.0039

Table 4.8 Determinants of observed market reactions (Industry, country and time effects) (Continued)

Panel B: Average abnormal returns are measured over the (-1; +3) event window

	(1)	(2)	(3)	(4)
Allocated EUAs	0.00000			
Verified emissions		-0.00002		
Excess/Shortage EUAs			0.00013**	
Allocation factor				-0.00049
Installations	0.00002	0.00003	0.00004	0.00002
Capitalization	-0.00020	-0.00020	-0.00022	-0.00021
Debt-to-Equity	-0.00011**	-0.00011**	-0.00011**	-0.00011**
Consumer goods	0.00263	0.00258	0.00255	0.00223
Industrials	0.00211	0.00211	0.00201	0.00171
Basic materials	0.00211	0.00208	0.00201	0.00174
Utilities	0.00111	0.00130	0.00158	0.00071
Oil & Gas	-0.00281	-0.00277	-0.00294	-0.00318
Healthcare	-0.00018	-0.00021	-0.00020	-0.00050
Technology	0.00575	0.00576	0.00574	0.00544
Telecommunications	0.01053*	0.01053*	0.01057*	0.01000**
United Kingdom	0.00021	0.00016	0.00015	0.00024
2006	0.00316*	0.00319*	0.00318*	0.00317*
2007	0.00145	0.00147	0.00146	0.00154
2008	0.00652*	0.00653*	0.00665*	0.00653*
2009	0.00269*	0.00270*	0.00275*	0.00283*
2010	0.00370*	0.00371*	0.00379*	0.00379*
Constant	-0.00127	-0.00135	-0.00115	-0.00019
Observations	407	407	407	407
R-squared	10.71%	10.75%	11.16%	10.88%
Wald Chi-squared (18df)	40.17	41.06	43.91	40.5
p-value	0.002	0.0015	0.0006	0.0018

4.6.5. Evaluation of the environmental effectiveness of the EU ETS

The analysis proceeds with an evaluation of the cap-and-trade programme's environmental effectiveness. Table 4.9 reports that firms in all industries but Financials, Technology and Telecommunications mostly reduced their intensities over the period 2006 - 2011. Out of 334 firm year observations, 236 registered carbon intensity reductions. More importantly, the abnormal returns observed on the day of emissions data publication were on average negative for those firms which reduced their carbon intensity in the following year, respectively -0.054% and -0.034% for the (0; +1) and (-1; +3) event windows. Mean abnormal returns were positive for those companies which in the next year increased their carbon intensity (0.138% for the short window and 0.191% for the long event window).

Table 4.9 Changes in emissions intensity across industries

This table reports the direction of emissions intensity change over the 334 firm years covered by the dataset from January 2006 until June 2011. Average abnormal returns (AARs) and their standard deviations are calculated separately for the instances when firms reduced their intensities and when they increased their intensities. Abnormal returns are estimated over both the (0; +1) and the (-1; +3) event windows.

	Intensity Reduction		
	Yes	**No**	**Summary**
Financials	1	1	2
Consumer goods	56	25	81
Industrials	49	30	79
Basic materials	41	9	50
Utilities	39	15	54
Oil & Gas	16	6	22
Healthcare	25	4	29
Technology	6	6	12
Telecommunications	3	2	5
Total sample	236	98	334
AAR (0; +1) from previous year	-0.054%	0.138%	0.002%
St. Dev. AAR (0; +1)	1.11%	1.33%	1.18%
AARs (-1; +3) from previous year	-0.034%	0.191%	0.032%
St. Dev. AAR (-1; +3)	0.83%	1.12%	0.93%

To confirm the causality, the logistic regression specified in Equation 8 is estimated, where the change in intensity is modelled as a function of abnormal returns experienced upon verified emissions release in the previous year. The specification of the logistic model is confirmed by a Wald test for the joint significance of all independent variables. In addition, goodness of fit is assessed by a Hosmer and Lemeshow test (for robustness, the results of separating the dataset into 4 and 10 groups is reported). Chi-squared statistics and corresponding p-values are reported in Table 4.10 below. The negative regression coefficient of abnormal returns implies that the log of the odds of a firm reducing its intensity is negatively related to abnormal returns. The lower the abnormal returns are, the more likely it is for a firm to subsequently reduce its emissions intensity.

For a 1% reduction in the abnormal returns experienced following the ETS report publication, the expected change in the log odds of a firm improving its carbon performance increases by 13.314 for the (0; +1) event window and by 11.34 for the (-1; +3) event window. While in line with Hypothesis 5, the results are statistically insignificant. The odds ratios are virtually indistinguishable from zero which implies a nil chance of intensity reduction following a significant negative market response. In brief, no conclusive evidence is found that the likelihood of a firm reducing its intensity is related to the market reaction experienced following the release of carbon performance data. This finding is intuitive, especially in light of the primarily insignificant market reactions associated with the verified emissions report publications.

The fact that abnormal returns were on average negative for companies which reduced their intensity in the following year (see Table 4.9) appears to have been spurious. In 70.66% of

Table 4.10 Modelling emissions intensity reductions as a function of abnormal returns
This table reports the results of the logistic regression in Equation 8. Robust standard errors are used.

Panel A: Abnormal returns are estimated over the (0; +1) event window.

	β	SE	Wald's χ2	df	p-value	e^β (odds ratio)
AR (o; +1)	-13.314	10.4906	1.61	1	0.2044	0.0000
Consumer goods	0.2694	1.3588	0.04	1	0.8429	1.3091
Industrials	-0.0843	1.3538	0.00	1	0.9503	0.9192
Basic materials	1.0352	1.3743	0.57	1	0.4513	2.8158
Utilities	0.3615	1.3676	0.07	1	0.7915	1.4354
Oil & Gas	0.2325	1.4387	0.03	1	0.8716	1.2618
Healthcare	1.2928	1.4252	0.82	1	0.3644	3.6430
Technology	-0.6498	1.4486	0.20	1	0.6538	0.5222
Telecommunications	-0.1618	1.7239	0.01	1	0.9252	0.8506
United Kingdom	0.0108	0.2747	0.00	1	0.9688	1.0108
2007	-0.9892	0.5351	3.42	1	0.0645	0.3719
2008	-1.3860	0.5204	7.09	1	0.0077	0.2501
2009	-1.7308	0.5065	11.68	1	0.0006	0.1771
2010	-2.2335	0.5036	19.67	1	0.0000	0.1072
Constant	1.9753	1.4143	1.95	1	0.1625	7.2091

Overall model evaluation	χ2	df	p-value
Wald test	41.58	14	0.0001
Goodness-of-fit			
Hosmer & Lemeshow (10 groups)	10.99	8	0.202
Hosmer & Lemeshow (4 groups)	1.79	2	0.408

Panel B: abnormal returns estimated over the (-1; +3) event window.

	β	SE	Wald's χ2	df	p-value	e^β (log odds)
AR (-1; +3)	-11.3400	13.8134	0.67	1	0.4117	0.0000
Consumer goods	0.2795	1.3082	0.05	1	0.8308	1.3225
Industrials	-0.0337	1.3027	0.00	1	0.9794	0.9669
Basic materials	1.0537	1.3241	0.63	1	0.4264	2.8682
Utilities	0.4326	1.3148	0.11	1	0.7421	1.5413
Oil & Gas	0.3172	1.3848	0.05	1	0.8188	1.3733
Healthcare	1.3473	1.3737	0.96	1	0.3267	3.8470
Technology	-0.4676	1.4024	0.11	1	0.7388	0.6265
Telecommunications	-0.1143	1.7082	0.00	1	0.9467	0.8920
UK	0.0024	0.2739	0.00	1	0.9931	1.0024
2007	-0.9888	0.5354	3.41	1	0.0648	0.3720
2008	-1.3618	0.5220	6.80	1	0.0091	0.2562
2009	-1.6732	0.5193	10.38	1	0.0013	0.1876
2010	-2.2130	0.5049	19.21	1	0.0000	0.1094
Constant	1.9128	1.3685	1.95	1	0.1622	6.7723

Overall model evaluation	χ2	df	p-value
Wald test	40.96	14	0.0002
Goodness-of-fit			
Hosmer & Lemeshow (10 groups)	9.31	8	0.3165
Hosmer & Lemeshow (4 groups)	1.67	2	0.4349

all firm years companies reduced their emissions, a result which does not seem to have been driven by adverse stock price pressure on the covered companies.

Table 4.11 presents the observed and predicted frequencies for emissions intensity decreases. The prediction for companies that reduced their carbon intensities is more accurate than that for companies which increased their intensities. The proportion of correctly classified intensity reductions is very high - 90.68% for the (0; +1) event window and 91.95% for the (-1; +3) event window. The proportion of correctly classified intensity increases is 26.53% for both event windows. Due to the observed general trend of intensity reduction across companies, I find a high rate of false negatives which is the ratio of firms wrongly predicted to increase their emissions intensities divided by all firms believed to increase their emissions intensities. The respective ratios are 45.83% for event window (0; +1) and 42.22% for the (-1; +3) event window. This confirms that the observed intensity reductions were not driven by negative abnormal returns and they merely reflect the tendency towards emissions intensity decreases.

Table 4.11 Observed and fitted frequencies for emissions intensity reduction

	Event window (0; +1)			Event window (-1; +3)		
	Predicted			Predicted		
Observed	Yes	No	% Correct	Yes	No	% Correct
Yes	214	22	90.68%	217	19	91.95%
No	72	26	26.53%	72	26	26.53%
Correctly Classified			71.86%			72.75%

No evidence is found that investors have used the available verified emissions data to exert pressure on polluters and incentivize them to improve their carbon performance. As it stands today, the cap-and-trade programme does not appear to meet the socially desirable objective of promoting the move to a low-carbon economy. These conclusions are in line

Table 4.12 Modelling abnormal returns as a function of carbon performance
This table reports the results of an OLS with abnormal returns modelled as a function of the change in intensity over the year (Equation 9). Industry, country and time effects are separately controlled for. The Wald test is used to confirm the significance of regression coefficients. A total of 337 firm years is examined. Robust standard errors are used. ***, **, * denote significance at the 10%, 5% and 1% levels, respectively.

	Industry, country & time effects		**Industry & time effects**		**Industry effects**		**Time effects**	
	(o;1)	**(-1;3)**	**(o;1)**	**(-1; 3)**	**(o; 1)**	**(-1; 3)**	**(o;1)**	**(-1;3)**
Intensity	0.0000	0.0000*	0.0000***	0.0000*	0.0000	0.0000*	0.0000*	0.0000*
Consumer goods	0.0026	0.0039	0.0037	0.0041*	0.0032	0.0032***		
Industrials	0.0010	0.0039**	0.0020	0.0041**	0.0016	0.0033***		
Basic materials	0.0022	0.0029	0.0031	0.0030***	0.0027	0.0022		
Utilities	-0.0012	0.0027***	-0.0006	0.0028**	-0.0011	0.0019		
Oil & Gas	-0.0043	-0.0010	-0.0043	-0.0010	-0.0047	-0.0020		
Healthcare	-0.0018	0.0006	-0.0010	0.0007	-0.0015	-0.0001		
Technology	-0.0064	0.0099**	-0.0050	0.0102*	-0.0053	0.0092**		
Telecommunications	0.0044	0.0066**	0.0044	0.0066**	0.0039	0.0057		
United Kingdom	-0.0018	-0.0004						
2007	-0.0030***	-0.0017	-0.0030***	-0.0017			-0.0029***	-0.0016
2008	-0.0011	0.0039**	-0.0012	0.0039			-0.0010	0.0040***
2009	-0.0018	-0.0006	-0.0019	-0.0006			-0.0018	-0.0004
2010	0.0021	0.0008	0.0020	0.0008			0.0022	0.0009
Constant	0.0023	-0.0024	0.0006	-0.0027	0.0003	-0.0013	0.0018***	0.0005
F-statistic	3.02	14.71	3.20	15.9	3.31	16.37	4.29	35.65
p-value	0.0002	0.0000	0.0002	0.0000	0.0007	0.0000	0.0009	0.0000
R-squared	7.6%	10.06%	7.1%	10.02%	4.87%	5.39%	2.24%	4.7%

with Hoffman's (2007) observations about the impact of carbon prices on the investment activities of covered companies. In a case study of five power generators in Germany, the author reports that coverage by the ETS has spurred only a wave of small-scale retrofit activities introducing minor changes in existing installations in order to increase carbon efficiency. Limited impact is found on medium and long-term technology investments, such as changes in R&D spending or the portfolio choices of electricity generation.

To test whether the market provides financial incentives to companies to improve their carbon performance, I estimate a pooled OLS regression (Equation 9) where the observed market reaction at the event day is modelled as a function of the change in emissions intensity. Industry, country and time fixed effects are controlled for. The results, reported in Table 4.12, demonstrate that the regression coefficients of intensity change are mostly statistically significant but so small in magnitude that they are virtually indistinguishable from zero (even when rounding to 6 decimal places). No evidence is found to support Hypothesis 6 that the market rewards environmental leaders and punishes companies which continue to emit at increasing rates. The impact of carbon performance appears to be too immaterial to meaningfully impact investors' behaviour.

4.7. ROBUSTNESS CHECK

As a robustness check, an alternative formulation of the return-generating model for British and German companies is used in the SUR framework. As discussed in Section 4.4.1, a Fama-French model was not selected on the premise that some companies might use carbon performance as a part of their SRI strategy. However, participation in the EU ETS may not necessarily imply socially responsible behaviour. Under the scheme companies only have the obligation to report their actual emissions and surrender an equivalent amount of carbon allowances. To demonstrate that earlier findings are robust to changes in the priced risk factors in the return-generating model, Equations 1 and 2 are re-estimated after adding size and value premia to the explanatory variables. The new return-generating model for UK companies is:

$$R_{i,t} = \alpha_i + \beta_{i,1}R_{FTSE,t} + \beta_{i,2}R_{EUA,t} + \beta_{i,3}R_{Electricity,t} + \beta_{i,4}R_{FOREX,t} + s_i SMB_t + h_i HML_t + \sum_{a=1}^{A}\gamma_{i,a}D_{at} + u_{i,t} \quad (9)$$

The return-generating model for German companies is:

$$R_{i,t} = \alpha_i + \beta_{i,1}R_{DAX,t} + \beta_{i,2}R_{EUA,t} + \beta_{i,3}R_{Electricity,t} + \beta_{i,4}R_{FOREX,t} + s_i SMB_t + h_i HML_t + \sum_{a=1}^{A}\gamma_{i,a}D_{at} + u_{i,t} \quad (10)$$

where SMB_t is the difference in daily continuously compounded return between a small-cap and a large-cap portfolio and HML_t is the difference in daily continuously compounded return between a value and a growth portfolio. The MSCI Germany Small and Large cap indices are used for Germany, and the FTSE Small and Large cap indices are used for the United Kingdom. The MSCI Germany Value and Growth indices are used for Germany, and the FTSE Value and Growth indices are used for the United Kingdom. All data are sourced from Datastream.

Individual abnormal returns are reported in Appendix 4C but, for the purposes of brevity, this chapter does not report the regression output of all analysed companies. It is worth noting, however, that the average German company had a greater exposure to the size factor over the period 2006-2011 than the average British company. The regression

Table 4.13 Investor reactions to unanticipated changes in actual emissions (robustness check)
Average abnormal returns (AAR) are calculated as the mean market reactions to a specific verification event across firms. AARs are estimates over both (0; +1) and (-1; +3) event windows. The Wald test is used to establish the significance of the abnormal return estimates. ***, **, * denotes significance at the 10%, 5% and 1% level, respectively.

	Actual > Expected emissions			Actual < Expected emissions		
	AR (o; +1)	**AR (-1; +3)**	**Firms**	**AR (o; +1)**	**AR (-1; +3)**	**Firms**
2005b	0.200%	0.052%	26	-0.131%	-0.190%	38
2006	-0.067%	0.018%	6	0.212%	0.044%	58
2007	-0.251%	-0.168%	13	-0.021%	-0.180%	51
2008	0.492*	0.878%*	18	-0.125%*	0.133%*	53
2009	-0.100%	-0.01%	27	-0.033%	-0.107	45
2010	0.193%	0.084%	28	-0.021%	-0.017%	44

Table 4.14 Investor reactions to unanticipated changes in the net EUA positions (robustness check)
Average abnormal returns (AAR) are calculated as the mean market reactions to a specific verification event across firms. AARs are estimates over both (0; +1) and (-1; +3) event windows. The Wald test is used to establish the significance of the abnormal return estimates. ***, **, * denotes significance at the 10%, 5% and 1% level, respectively.

	Good news			No news			Bad news		
	AR (o; +1)	**AR (-1; +3)**	**Firms**	**AR (o; +1)**	**AR (-1; +3)**	**Firms**	**AR (o; +1)**	**AR (-1; +3)**	**Firms**
2006	0.09%	-0.11%	17	0.24%	0.11%	46	-0.58%	-0.54%	1
2007	-0.19%	-0.22%	16	-0.01%	-0.16%	46	-0.03%	-0.21%	1
2008	0.355%**	1.057%*	12	0.187%*	0.230%*	48	-1.694**	0.368%*	6
2009	-0.04%	-0.12%	5	-0.08%	-0.06%	64	0.36%	-0.11%	3
2010	0.05%	-0.04%	9	0.04%	0.06%	59	0.40%	-0.43%	4

coefficient of the SMB variable is 0.45 for both event windows in Germany and only 0.17 in the United Kingdom. The results also show that the average company in Germany exhibited an almost negligible value bias (β_{HML}=0.01 for both event windows) while the average British company had a growth bias (β_{HML}= -0.13). The relationship between the returns of covered companies and all other independent variables is maintained after the introduction of the two Fama-French factors. The re-estimated results of Hypothesis 1 are summarized in Table 4.13. A comparison with Table 4.4 demonstrates that there are no quantitative and qualitative changes in the results. This suggests that the return-generating model is specified accurately and the results are robust. The same conclusions hold for the results of Hypothesis 2. A comparison between Tables 4.5 and 4.14 shows no changes in the results after the introduction of size and value premia in the return-generating model.

4.8. Conclusions

This chapter has examined the impact of mandatory environmental information disclosure on market value and carbon performance in the framework of the EU ETS. Limited evidence is found that firm-specific carbon performance matters for investors. The results of the event study demonstrate that only one out of the six verification events over the period 2006 -2011 has led to statistically significant market responses. Several possible explanations have been offered to account for the reported results. The lack of reaction to the first compliance event is attributed to market inefficiency in the early days of the scheme. Low carbon prices and an immaterial impact on the firm value may be the reason for the lack of reactions following the more recent verification events.

The only observed significant reaction, following the 2008 compliance event, offers more support to the hypothesis that investors react to unanticipated changes in the net EUA positions of companies rather than unanticipated changes in their level of actual emissions. The incremental information is not compounded instantaneously in the stock prices of covered companies and remains significant even when longer event window are used. This result suggests that policy-makers should improve the quality and quantity of data released to the general public in order to utilize the power of financial markets to stimulate socially desirable changes in the performance of companies. More focus on increasing the awareness of the public by disseminating information would be desirable.

No evidence is found to support the hypothesis that the observed market reactions are positively associated with the amount of freely allocated allowances and negatively associated with the amount of actual emissions. Both the level of free allowances and actual emissions during the year are found to be indistinguishable from zero as determinants of the stock price responses. The market reactions for high carbon-intensive companies are found to be larger, although not always significantly so, in magnitude than those for their less carbon-intensive counterparts. This result supports the hypothesis that carbon performance matters more for companies with high carbon-intensive activities. A caveat to the analysis is the short-term nature of the event study. Short-term reactions of market participants might differ substantially from the long-term view if investors are more focused on immediate profits/ losses and fail to account for the long-term cost-benefit analysis of environmental performance.

Despite the growing social awareness of anthropogenic climate change, the recent corporate trends of improving carbon footprints, and the dedicated political effort to move the EU to a lower-carbon economy, this chapter provides evidence that the scheme has had no material effect on the stock performance of covered companies and has not brought about the hoped for changes in their carbon performance. Contrary to expectations, I find that companies which experienced negative market reactions following the release of their actual emissions do not alter their carbon performance in the following year. Also, no evidence is found that the market reacts differently towards environmental leaders and laggards upon disclosure of their carbon emissions data. The analysis leads me to conclude that effective climate change mitigation and carbon emission reductions are not achievable via the EU ETS as it is presently constituted. The signal embedded in the price of carbon is not strong and credible enough to provoke investor action and improvement in corporate environmental performance.

Throughout the short life of the EU ETS, it has become apparent that setting up the emissions caps for the European countries is very challenging. Over-allocations in Phase I and sluggish economic activity as a consequence of the financial crisis and Eurozone debt woes in Phase II have adversely impacted carbon prices. Low carbon prices have questioned both the environmental effectiveness and the credible survival of the scheme. The inability of formal institutions to set tight limits on emissions, the slow decision making, and the overall regulatory uncertainty have undermined the functioning of the ETS and the willingness of financial markets to provide the necessary financial and behavioural incentives to polluting firms to alter their carbon performance. In short, the flaw lies with the way in which the EU ETS is structured, rather than with the underlying concept of emissions trading. Among the key changes in the structural design of the EU ETS which will be implemented during Phase III is the move to full auctioning of allowances in the power sector, which is responsible for the largest amount of carbon emissions. Therefore, the conclusions of this chapter may alter in a post-2012 context.

It is worth reiterating, however, that the results and conclusions reached in this chapter are entirely premised on two assumptions: 1. that the verified emissions reports represent genuine shocks to the market; and 2. that the employed models of expectations formation behaviour accurately reflect the way in which market participants think about the levels of emissions expected by a given company. As discussed in Section 4.3, it is possible that information about the emissions levels is released prior to the report publications. In addition, given the depressed carbon price, the quantitative impact on firm valuations may be too small to be considered market-moving by investors. The results therefore need to be interpreted with caution.

APPENDIX 4A LIST OF SAMPLE COMPANIES

Germany			United Kingdom		
1.	Heidelbergcement	Industrials	1.	National Grid	Utilities
2.	Suedzucker	Consumer Goods	2.	AstraZeneca	Healthcare
3.	Dyckerhoff	Industrials	3.	BAE Systems	Industrials
4.	Carl Zeizz	Healthcare	4.	Barclays	Financials
5.	Fresenius Medical	Healthcare	5.	Croda Internaitonal	Basic materials
6.	E.on	Utilities	6.	BHP Billiton	Basic materials
7.	RWE	Utilities	7.	Dairy Crest Group	Consumer Goods
8.	Merck KGAA	Healthcare	8.	Rolls-Royce	Industrials
9.	Wincor Nixdorf	Technology	9.	Centrica	Utilities
10.	WMF Wuertt.	Consumer Goods	10.	BT Group	Telecommunications
11.	Sud-Chemie	Basic materials	11.	Drax	Utilities
12.	Bayer	Basic materials	12.	GlaxoSmithKline	Healthcare
13.	Henkel	Consumer Goods	13.	Serco	Industrials
14.	MTU Aero Engines	Industrials	14.	Severn Trent	Utilities
15.	Infineon Technologie	Technology	15.	Balfour Beatty	Industrials
16.	Heidelberger Druck.	Industrials	16.	Carillion	Industrials
17.	Siemens	Industrials	17.	Marston's	Consumer Goods
18.	K+S	Basic materials	18.	Tate & Lyle	Consumer Goods
19.	Aurubis	Basic materials	19.	Johnson Matthey	Basic materials
20.	Porsche Automobil	Consumer goods	20.	Anglo-American	Basic materials
21.	BMW	Consumer goods	21.	Associated British	Consumer Goods
22.	Pfleiderer	Industrials	22.	BP PLC	Oil & Gas
23.	Linde	Basic materials	23.	Scottish & Southern	Utilities
24.	Audi	Consumer goods	24.	Diageo	Consumer goods
25.	BASF SE	Basic materials	25.	Premier Oil	Oil & Gas
26.	ThysssenKrupp	Industrials	26.	Premier Foods	Consumer Goods
27.	Villeroy & Boch	Industrials	27.	International Power	Utilities
28.	MVV Energie	Utilities	28.	Babcock	Industrials
29.	Daimler	Consumer goods	29.	BG Group	Oil & Gas
30.	Hochtief	Industrials	30.	Smith & Nephew	Healthcare
31.	MAN SE	Industrials	31.	De La Rue	Industrials
32.	Salzgitter	Basic materials	32.	DS Smith	Industrials
33.	Continental	Consumer Goods	33.	Tullow Oil	Oil & Gas
34.	Deutsche Lufthansa	Consumer goods	34.	Greene King	Consumer Goods
35.	EnBW Energie	Utilities	35.	Rio Tinto	Basic materials
36.	Volkswagen	Consumer goods	36.	British American	Consumer Goods
			37.	Filtronic	Technology
			38.	Elementis	Basic materials
			39.	Imperial Tobacco	Consumer Goods
			40.	United Utilities	Utilities
			41.	Royal Dutch Shell	Oil & Gas

Appendix 4B Firm-level abnormal return estimates

Event window (0; +1)

	VER05A	VER05B	VER06	VER07	VER08	VER09	VER10	R^2
HEI		-0.0175	-0.0001	0.0022	-0.0051	0.0020	0.0069	32.73%
SZU	0.0017	-0.0194***	0.0098	-0.0116	0.0192	0.0011	0.0049	23.58%
DYK	-0.0121	-0.0028	-0.0014	0.0017	0.0241***	0.0039	-0.0066	2.42%
AFX	-0.0291***		0.0089	-0.0024	-0.0208	-0.0050	0.0128	10.02%
FME	0.0017	-0.0033	0.0093	0.0070	-0.0131	-0.0047	0.0076	13.97%
EOAN	-0.0088	-0.0030	0.0279*	-0.0019	-0.0129	-0.0013	-0.0021	48.27%
RWE	-0.0201**		0.0083	-0.0002	-0.0146	-0.0029	0.0068	44.22%
MRK	0.0018	-0.0145	0.0008	-0.0017	-0.0016	-0.0037	0.0107	17.96%
WIN	-0.0044	-0.0031	-0.0063	-0.0137	0.0237***	-0.0032	0.0096	31.57%
WMF	0.0028	-0.0051	0.0135	0.0072	-0.0092	0.0197	-0.0042	3.22%
SUC	0.0121	-0.0042						2.04%
BAYN	-0.0037	-0.0106	-0.0036	-0.0004	-0.0241**	-0.0005	0.0098	45.95%
HEN	-0.0039	-0.0054	0.0004	-0.0006	0.0029	0.0047	0.0023	30.50%
MTX	0.0075	-0.0008	-0.0019	-0.0164	0.0356**	0.0000	0.0288***	32.62%
IFX		0.0112	-0.0073	0.0054	-0.0423***	-0.0066	0.0210	23.12%
HDD	-0.0100	0.0024	0.0077	0.0002	-0.0061	0.0129	0.0158	30.52%
SIE	0.0023	0.0107	-0.0009	-0.0127	-0.0214**	-0.0001	0.0013	58.54%
SDF	0.0035	0.0193	0.0065	0.0146	0.0055	-0.0151	0.0186	32.19%
NDA	0.0002	-0.0097	0.0008	-0.0120	0.0054	0.0096	0.0122	35.75%
PAH3	0.0046	0.0032	0.0142	-0.0202	0.0173	0.0015	0.0014	39.06%
BMW	-0.0061	0.0087		0.0007	0.0537*	0.0061	0.0147	50.85%
PFD4	-0.0126	0.0018	-0.0117			0.0118		12.26%
LIN						-0.0050	0.0093	45.41%
NSU	-0.0044	-0.0020	0.0093	-0.0062	0.0156	-0.0085	-0.0017	5.14%
BAS	-0.0137***	0.0046	-0.0031	0.0008	0.0049	0.0028	0.0011	63.14%
TKA	-0.0111	-0.0227***	-0.0077	0.0051	0.0146	-0.0025	0.0155	55.35%
VIB3	-0.0018	0.0006	-0.0060	-0.0184	-0.0181	-0.0154	0.0270	5.45%
MVV1	0.0119	-0.0111	0.0065	-0.0129	-0.0181***	-0.0060	-0.0013	4.42%
DAI		0.0089	-0.0031	-0.0105	0.0201***	-0.0042	0.0156	58.87%
HOT	-0.0196		0.0143	0.0351**	-0.0077	-0.0014	0.0048	44.06%
MAN	-0.0194	-0.0012	-0.0037	0.0019	0.0257**	-0.0053	0.0090	52.01%
SZG	-0.0159	-0.0119	0.0076	0.0100	0.0022	-0.0101	0.0247	49.68%
CON	-0.0098	0.0058	0.0061	0.0066	0.0245	-0.0063	0.0108	27.43%
LHA	-0.0038	0.0095	0.0019	-0.0034	-0.0051	0.0091	-0.0016	44.44%
EBK	0.0049	-0.0091	0.0007	0.0032	-0.0083	-0.0003	-0.0027	1.54%
VOW	0.0212	-0.0102	-0.0155	0.0059	0.0095	-0.0028	-0.0065	8.98%
NG	0.0007	0.0099	0.0086	0.0066	-0.0063	0.0013	-0.0022	32.88%
AZN	-0.0014	0.0048	-0.0039	0.0083	-0.0111	-0.0016	-0.0008	33.04%
BA	-0.0054	-0.0120	0.0009	0.0030	-0.0069	-0.0010	0.0016	37.41%
BARC					0.0079	-0.0073	0.0002	42.61%
CRDA	0.0072	0.0116	-0.0001	0.0112	0.0158	0.0013	0.0024	33.34%
BLT	0.0016	-0.0093	0.0017	0.0070	-0.0008	-0.0023	0.0003	62.95%
DCG	0.0124	-0.0013	-0.0044	0.0058	0.0397*	-0.0054	-0.0017	14.29%
RR	-0.0036	-0.0127			0.0319*	0.0061	-0.0022	53.11%

CNA	0.0046	-0.0123	0.0045	0.0004	-0.0154	0.0027	0.0025	26.49%
BTA	0.0079	0.0075	0.0090	0.0090	0.0072	-0.0008	-0.0037	33.48%
DRXG	-0.0133	-0.0143	-0.0060	-0.0068	-0.0091	0.0023	0.0142	19.63%
GSK	0.0031	0.0034	-0.0021	0.0031	-0.0162**	-0.0057	0.0034	28.52%
SERC					-0.0120	-0.0021	-0.0108	29.13%
SVT	0.0029	0.0051	0.0059	-0.0054	-0.0159***	0.0020	-0.0012	30.99%
BBY	-0.0095	0.0032	0.0069	-0.0282*	0.0198***	0.0006	-0.0121	41.68%
CLLN	-0.0439*	0.0092	0.0008	-0.0158	0.0050	0.0065	-0.0028	37.64%
MARS					0.0069	0.0064	0.0074	27.77%
TATE	0.0062	-0.0029	0.0050	-0.0085	0.0140	0.0038	-0.0107	17.35%
JMAT					0.0165	0.0042	0.0084	51.80%
AAL					0.0091		-0.0018	62.92%
ABF				-0.0065	0.0036	-0.0013	-0.0031	34.21%
BP	-0.0099	-0.0105	-0.0064	0.0061	-0.0228**	0.0002	0.0075	50.60%
SSE	-0.0009	0.0091	0.0099	-0.0040	-0.0233*	-0.0024	0.0067	32.59%
DGE	0.0004	-0.0005	0.0001	0.0008	-0.0053	0.0042	-0.0057	44.66%
PMO	-0.0021	-0.0240***	-0.0065	-0.0041	-0.0090	0.0049	0.0123	34.56%
PFD	0.0066	0.0116	0.0031	0.0030			0.0390	11.60%
IPR	-0.0111	0.0003	0.0126	0.0145	-0.0013	0.0014	-0.0052	34.93%
BAB	-0.0022	-0.0052	0.0004	-0.0110	-0.0211***	0.0039	-0.0057	20.95%
BG	-0.0109	0.0045	-0.0066					50.30%
SN	-0.0109	0.0081	-0.0005	-0.0062	0.0027	-0.0073	-0.0017	27.16%
DLAR					-0.0266**	0.0043	-0.0019	08.58%
SMDS	-0.0163	0.0162	0.0062	-0.0078	0.0441**	0.0064	0.0040	23.57%
TLW	0.0045	-0.0268***	-0.0022	-0.0155	-0.0361**	0.0028	0.0007	38.73%
GNK					0.0385*	0.0052	-0.0017	34.09%
RIO	0.0031	-0.0005	0.0051	0.0095	-0.0121	0.0010	0.0016	51.51%
BATS	-0.0006	0.0022	-0.0034	-0.0096				28.69%
FTC					-0.0197	-0.0021	-0.0388	3.83%
ELM	-0.0117	0.0269	0.0024	-0.0029	0.0195	-0.0052		13.10%
IMT	-0.0028	-0.0017	-0.0046	-0.0045	-0.0041	-0.0039	0.0032	24.36%
UU	0.0013	0.0049	0.0018	-0.0006	-0.0122	0.0040	0.0001	35.55%
RDSB	-0.0021	-0.0051	-0.0082	0.0068	-0.0127***	-0.0024	-0.0027	63.34%

Event window (-1; +3)

	VER05A	VER05B	VER06	VER07	VER08	VER09	VER10	R^2
HEI		-0.0139	0.0022	-0.0060	0.0430*	-0.0029	-0.0028	33.54%
SZU	0.0018	-0.0155**	0.0089	0.0057	0.0056	-0.0056	-0.0011	23.59%
DYK	-0.0045	-0.0032	-0.0025	-0.0014	-0.0024	-0.0080	-0.0034	2.29%
AFX	-0.0105		-0.0009	-0.0014	-0.0148	-0.0065	0.0023	9.94%
FME	0.0026	-0.0016	0.0015	0.0028	-0.0139**	-0.0009	0.0026	14.12%
EOAN	0.0031	-0.0008	0.0094	-0.0016	-0.0049	-0.0020	0.0014	48.08%
RWE	-0.0110***		0.0044	-0.0006	-0.0071	-0.0019	0.0028	44.17%
MRK	0.0146**	-0.0164**	0.0011	0.0003	-0.0082	-0.0009	0.0058	18.45%
WIN	0.0018	-0.0108	-0.0063	0.0032	0.0108	0.0022	0.0025	31.58%
WMF	0.0139	-0.0036	0.0059	-0.0026	-0.0002	0.0021	-0.0031	3.19%
SUC	0.0040	-0.0045						2.00%
BAYN	0.0099	-0.0016	0.0004	-0.0037	-0.0128**	-0.0046	-0.0024	45.94%
HEN	0.0011	-0.0024	-0.0019	-0.0049	0.0036	0.0083	0.0023	30.60%
MTX	0.0049	-0.0054	-0.0068	0.0016	0.0258*	0.0100	0.0040	32.81%
IFX		0.0003	-0.0030	0.0144	0.0484*	0.0022	0.0096	23.71%
HDD	0.0005	-0.0009	-0.0010	-0.0167	0.0270**	0.0090	-0.0012	30.98%
SIE	-0.0030	0.0082	0.0032	-0.0015	-0.0069	0.0028	-0.0004	58.47%
SDF	0.0144	0.0024	0.0071	0.0050	0.0071	-0.0079	0.0059	32.33%
NDA	-0.0122	-0.0050	-0.0109	0.0038	0.0042	0.0070	0.0082	35.90%
PAH3	0.0026	0.0007	-0.0060	-0.0191***	0.0124	0.0024	-0.0091	39.21%
BMW	-0.0032	0.0004		-0.0017	0.0087	0.0057	0.0027	50.23%
PFD4	0.0115	-0.0046	-0.0052			0.0079		12.29%
LIN						-0.0029	0.0048	45.43%
NSU	0.0048	-0.0048	0.0047	-0.0006	0.0046	-0.0078	-0.0035	5.12%
BAS	-0.0032	0.0031	0.0008	0.0001	0.0081	0.0014	0.0073	63.24%
TKA	-0.0032	0.0011	-0.0029	-0.0027	0.0163**	0.0046	0.0065	55.34%
VIB3	-0.0023	-0.0039	-0.0129	-0.0014	-0.0010	-0.0027	0.0152	5.34%
MVV1	0.0130***	-0.0130***	0.0030	-0.0050	-0.0054	-0.0011	-0.0004	4.50%
DAI		0.0044	-0.0031	-0.0128***	0.0116***	0.0006	0.0094	58.99%
HOT	0.0009		0.0076	0.0096	0.0131	0.0008	0.0002	44.06%
MAN	-0.0037	-0.0076	-0.0022	0.0021	0.0047	0.0052	0.0065	51.97%
SZG	-0.0048	-0.0035	0.0026	-0.0053	0.0058	-0.0004	0.0097	49.71%
CON	0.0000	-0.0003	-0.0010	0.0045	0.0427*	-0.0031	-0.0012	28.05%
LHA	0.0056	-0.0076	0.0069	0.0000	0.0052	0.0042	-0.0027	44.58%
EBK	-0.0002	-0.0025	-0.0015	-0.0007	-0.0026	0.0056	-0.0005	1.48%
VOW	-0.0068	-0.0095	-0.0088	0.0001	-0.0025	0.0061	-0.0023	9.06%
NG	0.0037	0.0101***	0.0034	0.0016	-0.0027	0.0002	-0.0039	32.92%
AZN	0.0025	0.0009	-0.0009	0.0127**	-0.0036	-0.0017	-0.0001	33.16%
BA	-0.0025	-0.0096	-0.0033	-0.0020	-0.0061	-0.0064	-0.0016	37.53%
BARC					-0.0002	-0.0047	0.0009	42.59%
CRDA	0.0062	-0.0004	-0.0056	-0.0042	-0.0024	-0.0048	0.0039	33.35%
BLT	-0.0025	-0.0001	-0.0003	0.0086	-0.0116	-0.0034	0.0020	62.91%
DCG	0.0101	-0.0084	0.0029	-0.0096	0.0204**	0.0022	-0.0026	14.34%
RR	-0.0015	-0.0083			0.0144**	0.0025	-0.0018	52.96%
CNA	0.0031	-0.0094	0.0070	0.0045	0.0028	-0.0016	-0.0066	26.54%
BTA	0.0093	0.0215*	0.0034	0.0013	0.0178**	-0.0019	0.0012	34.04%
DRXG	-0.0029	-0.0073	-0.0008	0.0005	0.0029	-0.0054	0.0091	19.51%

GSK	0.0108**	0.0038	0.0020	0.0065	-0.0052	-0.0010	0.0005	28.62%
SERC					-0.0057	0.0008	-0.0076	29.12%
SVT	-0.0008	-0.0041	0.0016	-0.0038	0.0084	0.0001	-0.0049	30.85%
BBY	-0.0105	-0.0056	0.0057	-0.0114***	0.0107	-0.0028	-0.0074	41.61%
CLLN	-0.0151**	0.0023	0.0050	-0.0108	0.0067	0.0022	0.0028	37.30%
MARS					0.0246*	-0.0052	0.0014	28.15%
TATE	0.0027	-0.0036	0.0049	-0.0109	0.0187**	-0.0003	0.0090	17.62%
JMAT					0.0067	0.0021	0.0045	51.76%
AAL					0.0150***		-0.0007	63.00%
ABF				-0.0028	0.0049	-0.0001	-0.0011	34.18%
BP	-0.0063	-0.0046	-0.0041	-0.0008	-0.0142**	0.0034	0.0051	50.59%
SSE	-0.0017	0.0000	0.0044	-0.0031	-0.0012	-0.0038	0.0018	32.07%
DGE	0.0012	-0.0014	0.0007	0.0024	0.0006	0.0010	0.0016	44.63%
PMO	-0.0004	-0.0143	-0.0064	-0.0016	-0.0083	0.0039	0.0067	34.57%
PFD	0.0156	0.0089	0.0130	0.0124			0.0177	11.69%
IPR	-0.0023	-0.0047	0.0072	0.0069	0.0154**	-0.0026	-0.0003	35.04%
BAB	-0.0045	0.0040	0.0077	-0.0048	-0.0147***	0.0045	-0.0016	20.94%
BG	-0.0084	0.0013	-0.0040					50.32%
SN	-0.0237*	-0.0008	-0.0050	-0.0040	-0.0094	-0.0042	0.0005	27.77%
DLAR					-0.0230*	-0.0039	-0.0009	8.78%
SMDS	-0.0014	0.0057	0.0095	-0.0094	0.0541*	-0.0024	-0.0014	24.43%
TLW	0.0063	-0.0246*	-0.0038	-0.0093	-0.0199**	0.0024	-0.0010	38.87%
GNK					0.0195**	-0.0033	-0.0052	34.02%
RIO	-0.0021	0.0020	0.0059	0.0073	-0.0389*	-0.0017	-0.0026	51.80%
BATS	-0.0005	0.0003	-0.0030	-0.0083				28.64%
FTC					-0.0114	0.0091	0.0017	3.68%
ELM	-0.0005	0.0053	0.0033	0.0008	0.0151	0.0130		13.13%
IMT	-0.0028	-0.0006	-0.0046	-0.0018	-0.0055	-0.0057	0.0026	24.50%
UU	-0.0009	0.0037	0.0023	-0.0016	0.0058	-0.0012	-0.0055	35.47%
RDSB	-0.0038	-0.0004	-0.0056	0.0011	-0.0127*	0.0014	-0.0010	63.43%

Appendix 4C Firm-level abnormal return estimates (robustness check)

Event window (0; +1)

	VER05A	**VER05B**	**VER06**	**VER07**	**VER08**	**VER09**	**VER10**	**R^2**
HEI		-0.0157	0.0005	0.0018	-0.0025	0.0009	0.0017	34.68%
SZU	0.0029	-0.0171	0.0103	-0.0102	0.0192	-0.0002	-0.0018	27.56%
DYK	-0.0114	-0.0008	-0.0009	0.0022	0.0239***	0.0037	-0.0101	3.19%
AFX	-0.0278***		0.0102	-0.0001	-0.0175	-0.0070	0.0049	15.99%
FME	0.0011	-0.0032	0.0094	0.0082	-0.0140	-0.0048	0.0072	13.97%
EOAN	-0.0093	-0.0033	0.0257*	-0.0004	-0.0204**	-0.0007	-0.0013	56.33%
RWE	-0.0204**		0.0060	0.0011	-0.0217**	-0.0023	0.0079	53.99%
MRK	0.0022	-0.0129	0.0004	-0.0001	-0.0039	-0.0044	0.0079	20.38%
WIN	-0.0029	-0.0007	-0.0052	-0.0119	0.0263**	-0.0052	-0.0002	38.75%
WMF	0.0033	-0.0040	0.0138	0.0068	-0.0090	0.0193	-0.0060	3.55%
SUC	0.0128	-0.0027						2.75%
BAYN	-0.0038	-0.0102	-0.0039	0.0000	-0.0263*	-0.0004	0.0096	46.67%
HEN	-0.0036	-0.0040	0.0005	0.0006	0.0021	0.0037	-0.0026	33.17%
MTX	0.0102	0.0043	-0.0014	-0.0131	0.0363**	-0.0028	0.0153	44.20%
IFX		0.0171	-0.0070	0.0087	-0.0401***	-0.0103	0.0058	31.04%
HDD	-0.0069	0.0074	0.0082	0.0030	-0.0029	0.0098	0.0019	39.44%
SIE	0.0027	0.0121	-0.0010	-0.0105	-0.0232**	-0.0007	-0.0042	61.86%
SDF	0.0048	0.0234	0.0092	0.0173	0.0097	-0.0169	0.0066	39.89%
NDA	0.0022	-0.0048	0.0017	-0.0092	0.0070	0.0076	0.0014	44.44%
PAH3	0.0053	0.0050	0.0142	-0.0183	0.0159	-0.0002	-0.0081	43.77%
BMW	-0.0059	0.0087		0.0021	0.0526*	0.0050	0.0103	53.85%
PFD4	-0.0092	0.0089	-0.0111			0.0085		17.94%
LIN						-0.0056	0.0058	48.30%
NSU	-0.0029	-0.0002	0.0089	-0.0057	0.0152	-0.0097	-0.0061	9.28%
BAS	-0.0134***	0.0053	-0.0041	0.0018	0.0011	0.0027	-0.0012	66.82%
TKA	-0.0098	-0.0200***	-0.0069	0.0070	0.0147	-0.0040	0.0063	61.73%
VIB3	-0.0003	0.0054	-0.0047	-0.0174	-0.0157	-0.0166	0.0200	8.10%
MVV1	0.0125	-0.0096	0.0066	-0.0123	-0.0192***	-0.0064	-0.0041	5.19%
DAI		0.0101	-0.0042	-0.0084	0.0156	-0.0049	0.0101	64.27%
HOT	-0.0173		0.0145	0.0379*	-0.0062	-0.0038	-0.0068	52.50%
MAN	-0.0184	-0.0001	-0.0038	0.0042	0.0255**	-0.0071	-0.0004	58.43%
SZG	-0.0138	-0.0068	0.0092	0.0131	0.0050	-0.0124	0.0109	59.39%
CON	-0.0092	0.0061	0.0060	0.0075	0.0229	-0.0081	0.0038	30.78%
LHA	-0.0028	0.0104	0.0006	-0.0019	-0.0079	0.0078	-0.0076	51.69%
EBK	0.0053	-0.0080	0.0003	0.0037	-0.0095	-0.0005	-0.0036	2.18%
VOW	0.0162	-0.0174	-0.0047	-0.0036	0.0380**	-0.0004	0.0125	61.81%
NG	-0.0002	0.0076	0.0081	0.0075	-0.0032	0.0003	-0.0007	35.85%
AZN	-0.0028	0.0003	-0.0055	0.0091	-0.0063	-0.0036	0.0013	37.46%
BA	-0.0060	-0.0134	0.0003	0.0034	-0.0044	-0.0023	0.0030	38.77%
BARC					0.0016	-0.0032	0.0028	52.12%
CRDA	0.0083	0.0119	-0.0006	0.0109	0.0132	0.0012	-0.0022	34.97%
BLT	0.0015	-0.0110	0.0005	0.0071	0.0027	-0.0034	-0.0015	66.06%
DCG	0.0132	0.0009	-0.0045	0.0053	0.0358**	-0.0050	-0.0035	15.63%

RR	-0.0036	-0.0144			0.0334*	0.0053	-0.0032	53.22%
CNA	0.0038	-0.0154	0.0032	0.0011	-0.0123	0.0012	0.0031	28.73%
BTA	0.0078	0.0096	0.0099	0.0089	0.0059	0.0000	-0.0018	34.85%
DRXG	-0.0134	-0.0130	-0.0064	-0.0071	-0.0105	0.0024	0.0137	19.97%
GSK	0.0012	-0.0015	-0.0035	0.0041	-0.0104	-0.0079	0.0065	35.36%
SERC					-0.0128	-0.0028	-0.0121	31.95%
SVT	0.0024	0.0043	0.0058	-0.0052	-0.0150***	0.0017	-0.0007	31.59%
BBY	-0.0083	0.0060	0.0072	-0.0289*	0.0153	0.0011	-0.0152	43.88%
CLLN	-0.0422*	0.0142	0.0011	-0.0169	-0.0023	0.0074	-0.0072	42.05%
MARS					-0.0031	0.0079	0.0003	33.37%
TATE	0.0063	-0.0014	0.0049	-0.0091	0.0117	0.0039	-0.0107	18.02%
JMAT					0.0143	0.0044	0.0082	53.38%
AAL					0.0128		-0.0032	65.11%
ABF				-0.0064	0.0037	-0.0018	-0.0031	34.97%
BP	-0.0101	-0.0087	-0.0042	0.0062	-0.0221**	0.0017	0.0110	55.23%
SSE	-0.0012	0.0085	0.0095	-0.0033	-0.0222**	-0.0030	0.0070	33.91%
DGE	-0.0003	-0.0022	-0.0007	0.0012	-0.0041	0.0032	-0.0056	46.64%
PMO	0.0007	-0.0184	-0.0058	-0.0051	-0.0167	0.0065	0.0058	36.20%
PFD	0.0103	0.0249	0.0040	0.0007			0.0332	15.81%
IPR	-0.0111	0.0015	0.0121	0.0143	-0.0028	0.0011	-0.0063	36.08%
BAB	-0.0021	-0.0047	0.0000	-0.0114	-0.0231***	0.0036	-0.0077	22.72%
BG	-0.0113	0.0030	-0.0069					51.27%
SN	-0.0113	0.0083	-0.0010	-0.0060	0.0031	-0.0080	-0.0013	28.17%
DLAR					-0.0288**	0.0045	-0.0027	9.12%
SMDS	-0.0147	0.0214	0.0062	-0.0091	0.0356**	0.0077	-0.0005	26.52%
TLW	0.0059	-0.0246***	-0.0022	-0.0163	-0.0387*	0.0033	-0.0032	39.47%
GNK					0.0298**	0.0068	-0.0078	38.87%
RIO	0.0024	-0.0034	0.0027	0.0093	-0.0071	-0.0015	0.0005	57.52%
BATS	-0.0033	-0.0014	-0.0044	-0.0091				33.95%
FTC					-0.0254	-0.0010	-0.0430***	4.58%
ELM	-0.0093	0.0360***	0.0026	-0.0052	0.0080	-0.0036		17.67%
IMT	-0.0047	-0.0053	-0.0058	-0.0039	-0.0021	-0.0049	0.0036	29.19%
UU	0.0005	0.0040	0.0015	-0.0003	-0.0107	0.0034	0.0013	36.62%
RDSB	-0.0027	-0.0040	-0.0066	0.0070	-0.0113	-0.0015	0.0008	66.09%

Event window (-1; +3)

	VER05A	VER05B	VER06	VER07	VER08	VER09	VER10	R^2
HEI		-0.0113	0.0020	-0.0077	0.0436*	-0.0040	-0.0044	35.42%
SZU	0.0019	-0.0126***	0.0093	0.0044	0.0046	-0.0071	-0.0033	27.56%
DYK	-0.0043	-0.0010	-0.0023	-0.0017	-0.0029	-0.0085	-0.0045	3.07%
AFX	-0.0101		-0.0007	-0.0032	-0.0148	-0.0089	-0.0005	15.95%
FME	0.0022	-0.0016	0.0017	0.0032	-0.0147**	-0.0012	0.0023	14.12%
EOAN	0.0016	-0.0014	0.0102***	0.0000	-0.0077	-0.0018	0.0015	56.12%
RWE	-0.0124**		0.0050	0.0010	-0.0095***	-0.0015	0.0030	53.90%
MRK	0.0141**	-0.0147**	0.0015	0.0003	-0.0096	-0.0019	0.0047	20.86%
WIN	0.0021	-0.0070	-0.0060	0.0008	0.0107	0.0000	-0.0007	38.63%
WMF	0.0141	-0.0022	0.0055	-0.0037	-0.0009	0.0016	-0.0036	3.51%
SUC	0.0041	-0.0028						2.70%
BAYN	0.0097	-0.0013	0.0006	-0.0029	-0.0137**	-0.0046	-0.0025	46.63%
HEN	0.0009	-0.0006	-0.0016	-0.0060	0.0025	0.0070	0.0007	33.25%
MTX	0.0053	0.0011	-0.0062	-0.0011	0.0244*	0.0065	-0.0005	44.20%
IFX		0.0084	-0.0030	0.0104	0.0475*	-0.0021	0.0043	31.40%
HDD	0.0012	0.0059	-0.0008	-0.0201***	0.0270**	0.0054	-0.0059	39.77%
SIE	-0.0033	0.0099	0.0040	-0.0015	-0.0080	0.0019	-0.0023	61.80%
SDF	0.0152	0.0076	0.0080	0.0035	0.0072	-0.0102	0.0019	39.87%
NDA	-0.0120	0.0013	-0.0101	0.0021	0.0037	0.0045	0.0045	44.52%
PAH3	0.0027	0.0038	-0.0058	-0.0212**	0.0107	0.0002	-0.0123	43.91%
BMW	-0.0033	0.0012		-0.0028	0.0080	0.0044	0.0011	53.24%
PFD4	0.0122	0.0038	-0.0047			0.0039		17.94%
LIN						-0.0037	0.0035	48.30%
NSU	0.0049	-0.0022	0.0049	-0.0018	0.0043	-0.0091	-0.0050	9.24%
BAS	-0.0037	0.0038	0.0014	0.0008	0.0067	0.0011	0.0064	66.88%
TKA	-0.0031	0.0051	-0.0021	-0.0039	0.0154**	0.0027	0.0032	61.70%
VIB3	-0.0016	0.0016	-0.0130	-0.0031	-0.0015	-0.0042	0.0129	7.99%
MVV1	0.0129***	-0.0115***	0.0030	-0.0057	-0.0068	-0.0018	-0.0013	5.26%
DAI		0.0062	-0.0025	-0.0132**	0.0093	-0.0007	0.0074	64.37%
HOT	0.0012		0.0084	0.0076	0.0130	-0.0020	-0.0037	52.34%
MAN	-0.0038	-0.0051	-0.0016	0.0005	0.0042	0.0031	0.0033	58.30%
SZG	-0.0040	0.0030	0.0036	-0.0072	0.0055	-0.0034	0.0050	59.34%
CON	-0.0001	0.0018	-0.0006	0.0025	0.0414*	-0.0051	-0.0037	31.26%
LHA	0.0051	-0.0057	0.0070	-0.0014	0.0037	0.0026	-0.0048	51.68%
EBK	-0.0004	-0.0015	-0.0014	-0.0007	-0.0031	0.0053	-0.0008	2.10%
VOW	-0.0015	-0.0180	-0.0119	-0.0007	0.0093	0.0103	0.0047	61.78%
NG	0.0029	0.0080	0.0036	0.0009	0.0001	-0.0002	-0.0038	35.88%
AZN	0.0011	-0.0026	-0.0018	0.0106**	0.0004	-0.0031	0.0000	37.58%
BA	-0.0031	-0.0107***	-0.0037	-0.0027	-0.0043	-0.0073	-0.0015	38.89%
BARC					-0.0055	-0.0014	0.0030	52.14%
CRDA	0.0065	0.0007	-0.0064	-0.0046	-0.0046	-0.0053	0.0026	35.00%
BLT	-0.0028	-0.0006	-0.0014	0.0075	-0.0089	-0.0044	0.0008	65.99%
DCG	0.0103	-0.0068	0.0021	-0.0096	0.0170***	0.0020	-0.0028	15.60%
RR	-0.0015	-0.0093			0.0158**	0.0019	-0.0022	53.08%
CNA	0.0019	-0.0119***	0.0064	0.0028	0.0056	-0.0026	-0.0068	28.87%
BTA	0.0096	0.0227*	0.0040	0.0022	0.0164**	-0.0012	0.0020	35.39%

DRXG	-0.0031	-0.0064	-0.0015	0.0002	0.0013	-0.0057	0.0090	19.85%
GSK	0.0093**	-0.0002	0.0013	0.0044	-0.0005	-0.0023	0.0008	35.44%
SERC					-0.0068	-0.0001	-0.0081	31.94%
SVT	-0.0011	-0.0049	0.0016	-0.0041	0.0094***	-0.0001	-0.0048	31.60%
BBY	-0.0098	-0.0034	0.0050	-0.0109***	0.0067	-0.0031	-0.0080	43.72%
CLLN	-0.0143**	0.0063	0.0041	-0.0102	0.0003	0.0020	0.0020	41.60%
MARS					0.0166***	-0.0051	0.0000	33.48%
TATE	0.0028	-0.0026	0.0042	-0.0112	0.0164***	-0.0006	0.0092	18.23%
JMAT					0.0042	0.0018	0.0045	53.34%
AAL					0.0181**		-0.0017	65.21%
ABF				-0.0034	0.0049	-0.0006	-0.0012	34.95%
BP	-0.0054	-0.0038	-0.0016	0.0018	-0.0134**	0.0052	0.0064	55.18%
SSE	-0.0023	-0.0008	0.0044	-0.0036	0.0000	-0.0043	0.0017	33.53%
DGE	0.0006	-0.0027	0.0001	0.0012	0.0017	0.0003	0.0014	46.62%
PMO	0.0010	-0.0094	-0.0066	0.0000	-0.0146	0.0044	0.0053	36.22%
PFD	0.0173	0.0190	0.0109	0.0146			0.0172	15.95%
IPR	-0.0026	-0.0039	0.0063	0.0065	0.0140***	-0.0032	-0.0006	36.17%
BAB	-0.0044	0.0047	0.0067	-0.0050	-0.0169**	0.0038	-0.0022	22.76%
BG	-0.0089	0.0003	-0.0039					51.30%
SN	-0.0241*	-0.0008	-0.0057	-0.0046	-0.0093	-0.0049	0.0005	28.78%
DLAR					-0.0254*	-0.0041	-0.0009	9.37%
SMDS	-0.0005	0.0095	0.0079	-0.0089	0.0465*	-0.0026	-0.0022	27.09%
TLW	0.0070	-0.0225**	-0.0046	-0.0088	-0.0221**	0.0023	-0.0020	39.61%
GNK					0.0124	-0.0029	-0.0063	38.76%
RIO	-0.0031	0.0005	0.0029	0.0047	-0.0358*	-0.0039	-0.0038	57.78%
BATS	-0.0017	-0.0029	-0.0037	-0.0099***				33.96%
FTC					-0.0165	0.0092	0.0009	4.44%
ELM	0.0008	0.0124	0.0009	0.0017	0.0043	0.0127		17.61%
IMT	-0.0039	-0.0035	-0.0054	-0.0035	-0.0038	-0.0064	0.0024	29.30%
UU	-0.0014	0.0027	0.0023	-0.0021	0.0070	-0.0015	-0.0053	36.65%
RDSB	-0.0034	-0.0003	-0.0038	0.0030	-0.0115*	0.0026	0.0002	66.11%

CHAPTER 5 CONCLUSIONS, LIMITATIONS AND FUTURE RESEARCH

This thesis has examined three different aspects of the efficiency of the new European carbon market. The findings provide new empirical evidence about the information content of carbon options, investors' ability to respond to changes in the institutional framework and the value-relevance of carbon performance to firm valuations. The results are, however, subject to a number of limitations which suggest avenues for further research.

Chapter 2 demonstrates that the volatility embedded in carbon options traded on the European Climate Exchange is highly informative about future volatility up to a year ahead. It is also found to be a directionally accurate forecast of future variance. Implied volatility is shown to be both a biased forecast, as it overestimates ex-post realized volatility, and an inefficient forecast, as it does not subsume all information contained in historical volatility, particularly over short-term forecasting horizons. The conclusions about the inefficiency of implied volatility as a forecast may be reinforced by using more sophisticated forecasts derived from historical carbon prices. It was noted in Section 2.4.2. that there appears to be asymmetry in the way that carbon prices react to positive and negative shocks of the same magnitude. The use of volatility forecasts based on an EGARCH model or any other model which explicitly allows for differentiated responses to good and bad news would be one way to improve the empirical analysis. Alternatively, recent literature (e.g. Andersen and Bollerslev, 1998; Blair et al., 2001) has advocated the use of high-frequency data in modelling historical volatility-based forecasts. Due to the lack of access to such data, this thesis has not been able to employ such measures of carbon volatility.

Further research is also needed into the issue of whether implied volatility forecasts are in fact good or bad forecasts. Chapter 2 has focused on whether implied volatility is informative about future variance, or put simply, whether regulated companies and financial investors are justified in using option implied volatility as a forecast of how volatile carbon prices will be. I examine three features of the forecasts – their unbiasedness, their efficiency and their directional accuracy – but do not explicitly test the quality of the prediction. All conclusions are based on the coefficient of determination obtained from the conducted regression analyses. Ultimately, however, a biased forecast is not necessarily bad in and of itself – if the bias is persistent and known it can be easily taken into consideration by carbon market players.

Also, as noted in Section 2.6, the analysed time period overlaps with the recent financial crisis. The ensuing period of slow economic growth has led covered companies to sell off excess allowances in order to strengthen their balance sheets. Access to a longer data series will allow for the assessment of the impact of such short-term fluctuations on the relationship between implied and ex-post realized volatility. A re-examination of the information content of carbon options is needed when the depth and size of the market increase enough so that options with quarterly expiry are actively traded. The present concentration of liquidity in options on long-dated futures may partially explain the reported inefficiency of implied volatility forecasts. Similarly, the observed bias towards overestimating future volatility, which may be somewhat driven by the high level of uncertainty in the market due to its politically-motivated nature and susceptibility to regulatory changes, may be minimized when the EU ETS matures and confidence in its continuation grows.

Chapter 3 has examined the market sensitivity to announcements about the institutional design of the EU ETS. Market participants are found to incorporate new information regarding both supply and demand-side announcements, albeit failing to accurately assess the price impact on futures contracts with expirations in the different trading periods. The reactions are mostly small in magnitude, suggesting that much of the information may already be anticipated by the market and hence, do not represent true shocks .A diminished market sensitivity to institutional announcements and a disconnect between the carbon price and its fundamental drivers (extreme weather and energy prices) are documented following the onset of the financial crisis. This thesis has modelled carbon returns as a function of the broad market, the energy prices and extreme weather. To strengthen the conclusions of the chapter, carbon-generating models with alternative price determinants may be estimated. For example, Chevallier (2009) uses electricity as one source of priced risk, Alberola et al. (2008) and Koop and Tole (2011) use clean spreads and the switching EUA price, while Bonacina et al. (2009) add coal prices to their multifactor model.

There is room for further development in terms of the econometric structure of the return-generating process as well. Chapter 3 relies on ordinary least squares analysis where carbon is a linear function of the independent variables. More sophisticated distributed lag models may be used instead to better capture the impact of past carbon behaviour and past energy prices. For example, Miclaus et al. (2008) model carbon as an AR-GARCH process while Benz and Trück (2008) model carbon prices according to both AR-GARCH and Markov regime switching models. Fezzi and Bunn (2009) combine a structural vector autoregressive approach with co-integration and model the relationship between gas, electricity and carbon prices according to a structural, co-integrated vector error-correction model. Examination of the significance of price moves on days surrounding the actual announcements presents another area of future research. Significant cumulative event returns on days preceding the announcements might be indicative of information leakage (however unlikely) while significant returns on the following days may suggest a delayed response by market participants.

Chapter 4 looks at the stock price reactions of British and German companies upon mandatory emissions data releases over the period 2006 – 2011. No conclusive evidence is found that investors use information on the carbon performance of companies in their valuations. No change is found in the carbon performance of companies as a result of EU ETS compliance either. These results are attributed to the weak signal embedded in the carbon price and the context of known allowances oversupply. The move to auctioning, instead of giving away free allowances to covered companies, and the imminent EC intervention to remove excess EUAs from the market[36] suggest that ETS compliance will become more difficult and more expensive for companies. The pending changes in the institutional framework of the scheme may provide the needed incentives to provoke investor action. Therefore, the relevance of carbon performance for firm valuation needs to be re-examined when post-2012 data becomes available. Also, the chapter has offered two alternative hypotheses with regards to investor reactions upon carbon emissions publication – a response to the unanticipated level of emissions and a response to the unanticipated changes in the net EUA positions of covered companies. Supplementing the results with a

[36] European Commission, "Commission prepares for change of the timing for auctions of emission allowances". Available at: < http://ec.europa.eu/clima/news/articles/news_2012072501_en.htm>

qualitative study (for example, through a survey or an interview of market participants) may shed more light on how exactly investors form their expectations and to what extent they see carbon performance as a component of firm value.

Several additional caveats to the analysis are needed. First, the results are limited to the British and German market only. Extrapolating the inferences for all covered EU Member States may not be appropriate. Under the EU ETS, the less developed European countries, such as the former Eastern bloc countries, are allowed to increase their emissions levels while their more industrialized counterparts bear the emission reduction burden. For the former group of countries, the generous freely granted allowances may represent a considerable source of revenue relative to the market values of their companies (which are substantially smaller than the average British company, for example). Therefore, the conclusions from the German and British companies may not hold across the EU. Comprehensive research across countries is needed to establish if a differential impact of carbon performance exists. Second, the analysis in Chapter 4 has been limited to publicly-traded companies. The reported lack of carbon performance improvement following emissions disclosure may not necessarily represent the behaviour of the underlying population of public and private companies. Finally, as with Chapter 3, examination of market reactions on days before and after the actual report publication may provide insight into the speed with which investors respond to verified emissions data release. Exploring the direction of the causal association between carbon emissions levels and financial performance is also needed.

Overall, the evidence from the empirical analyses in Chapters 2, 3 and 4 lead me to conclude that currently the carbon market is not fully efficient. There are many possible explanations as to why the EU ETS is not efficient yet – the market is still young, trading in carbon is still thin and there is too much uncertainty about the future of Europe's environmental policies. It is my view, however, that the main reason behind the inefficiencies I document is the imperfect implementation of the emissions trading concept coupled with the unforeseen effects of the economic recession in Europe since 2008.

Because the market has been artificially created as a part of an environmental policy, it is extremely complex and inherently prone to uncertainty and instability. A mistake anywhere in the set-up of the scheme – be it proposed rules on future EUA allocations, misaligned incentives[37] for regulated companies, concerns about the continuation of the scheme, distributional unfairness across regulated sectors – risks undermining the entire market and its efficiency. A combination of such problems has plagued the scheme since its inception. First, regulators generously over-allocated emitters with free EUAs. Add to this the effects of the economic downturn following the financial crisis of 2008 and the market was soon oversupplied with permits, pushing the carbon price down and creating a disconnect with what should be its fundamental drivers. While a withdrawal of excess allowances from the market is currently debated, its critics argue that such an ex-post regulatory intervention will compromise the integrity of the market and will punish companies which have unused EUAs as a result of genuine abatement effort rather than excessive allocation. Such an intervention may scare investors away from the market, where risk-return trade-offs cannot be ascertained and governing rules change as a response to unforeseen developments. Policy uncertainty is a cost to regulated companies as well, where investments in carbon-

[37] For example, if allocations continue to be based mostly on historic emissions (as were most of the Phase I and II allocations), firms have no strong incentive to improve the carbon efficiency of their systems and processes.

reducing technology projects and improvements in energy efficiencies may be delayed or forgone altogether.

The cost of error in the EU ETS is high and failure to fulfil the intended socio-economic objectives risks making the market redundant. With carbon prices remaining low, companies may continue to pay little attention to their carbon performance, and investors may continue to disregard emissions in their financial valuations. Therefore the current levels of EUAs, coupled with the failure to agree on the future of the scheme[38] and seeming lack of commitment from many European member states (most notably the Eastern bloc countries which see the EU's environmental aspiration as a hurdle to their economic growth and development), raise perhaps the biggest concern – will the EU ETS last or will it follow the fate of the U.S. sulphur dioxide market, where regulation replaced the market-based mechanism for emissions reduction? Such an environment of heightened uncertainty may be one possible explanation for the inefficiencies reported in this thesis.

In conclusion, this thesis has offered some new empirical evidence into the efficiency of the European carbon market. The results are, however, subject to several limitations and there is room for further improvement. Availability of longer price series, particularly in the post-2012 context when major changes to the EU ETS are planned, will allow for the informational efficiency of the market to be re-examined.

[38] The inclusion of the aviation industry is the best illustration of this – although it was initially agreed that all airlines which use European airports will be covered by the EU ETS from 2012, the starting date was pushed to 2013 and then non-European airlines refused to comply and began lengthy negotiations with the aviation authorities.

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