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ESSAYS ON EUAS

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A mis padres, a mis hermanas y a mi lolo.

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Introduction

1. The European carbon market

The Kyoto Protocol, approved in December 1997, entered into force on February 16th, 2005, with the agreement of 141 countries. Linked to the United Nations Framework Convention on Climate Change (UNFCCC), this international agreement sets binding targets for reducing greenhouse gas emissions (henceforth, GHGE). Specifically, by ratifying the Kyoto Protocol, industrialized countries commit to reducing their global GHGE by at least 5% (8% for the EU) against 1990 levels over the period 2008-2012. Because of the Kyoto Protocol, carbon trading has been growing continuously.

The Directive 2003/87/EC of the European Parliament and of the European Council establishes that, as a mechanism of flexibility to achieve the reduction objectives for GHGE, the companies included in the directive (energy and industrial sectors) will receive entitlements at the beginning of each year, in order to cover their real verified emissions.[1] These permits, denominated European Union Allowances (EUAs), allow the owner to emit one tonne of carbon dioxide equivalent gas into the atmosphere. At the end of the control period, the firms covered by the environmental regulations have to check, report, and deliver to the governments a sufficient number of allowances to cover their verified real emissions for that year. If these companies emit more CO_2 than the allowances they own, they would have to go to the European Union Emission Trading Scheme (EU-ETS) and buy the difference. Those installations/countries that succeed in reducing their emissions are more likely to act as sellers of emission credits. Those installations/countries that fail in complying with their emission targets are more likely to act as buyers of emission credits. Failing to surrender

[1] The 2003/87/EC Directive includes the following sectors: combustion plants, oil refineries, coke ovens, iron and steel plants, factories making cement, glass, lime brick, tiles, pulp and paper, and other heavy industrial sectors.

the necessary emission credits will result in an excess emission penalty. The emission credits surrendered are immediately cancelled.

A compliance year equals a calendar year. On February 28th, the companies receive their permits. One month later, by March 31st, each company has to submit to the European Commission the verified emissions report corresponding to the previous year. By April 30th, the permits for the previous year must be surrendered. The European Commission has until May 15th, to make public those reports.

Although there were several prior experiences, the EU-ETS, that officially started on January 1st, 2005, is the largest of its kind in the world, both in terms of volume traded and in terms of polluting installations covered. The scheme is structured as a cap-and-trade system, meaning that total emissions are limited or 'capped', where the national cap and its allocation among the installations covered by the 2003/87/EC Directive are established by the National Allocation Plans (NAPs) of each Member State, until 2012. The NAP had to be presented no later than 18 months before the start of each "Phase", and had to be approved by the European Commission.[2] Accordingly, each Member State decided each year how to allocate the emission credits among the installations covered and about the possibility of banking and borrowing credits phases.[3]

So far, the EU-ETS has had three phases. Phase I was a pilot phase that started on January 1st, 2005 and ended up on December 31st, 2007; Phase II coincides with the Kyoto Protocol commitment period, from January 1st, 2008 to December 31st, 2012. There will be at least a Phase III, from January 1st, 2013 to December 31st, 2020. EUAs

[2] Each "Phase" represents a sequence of several years at once, in order to neutralize irregular CO_2 emissions.

[3] The allocation method in Phase III will differ: only one EU-wide emissions allocation will be elaborated, and each installation's individual allocation will be decided by the European Commission. Between 2005 and 2007 (2008 and 2012) a minimum of 95% (90%) of the emissions were freely allocated. The other 5% (10%) was auctioned. In Phase III, auctions will play a more prominent role. By 2020, it is estimated that more than 60% of allowances will be auctioned.

can be transferred between years within each phase. The “banking” facility allows participants to save surplus EUAs for use during a later compliance period. The “borrowing” facility is just the opposite. Banking was not allowed from Phase I to Phase II, although it is permitted from Phase II to Phase III. Borrowing is forbidden between phases. Therefore, a Phase I EUA is a different asset than a Phase II EUA. In each particular phase, banking and borrowing are both allowed between years.

The 2004/101/EC Directive settles the fundamentals of the project-based flexible mechanism, which authorizes EU members to generate and use Kyoto certificates from the so-called "project-based flexible mechanisms" to cover their domestic greenhouse gas emissions. Under this directive, the Clean Development Mechanism (CDM) provides that the countries included in Annex B of the Kyoto Protocol could exploit emissions-reduction projects in developing countries in order to generate credits, known as Certified Emission Reductions (CERs), which could be employed to meet their emissions targets under the Kyoto protocol. Each CER represents a successful emission reduction of one tonne of carbon dioxide. Although CERs are fully fungible with EUAs, their use is capped, with varying limits in each of the different countries.[4]

In addition, each Member State has to decide which percentage of CERs could be used instead of EUAs for borrowing and banking within the phase.[5] Unused CERs can be transferred from Phase II to Phase III. Not all the CERs can be used for

[4] Limits vary between 0% and 20%, depending on countries and sectors, with the average being about 13.5% (1,420Mt for the period 2008-2012).

[5] Concerning Phase II, in Latvia and Lithuania, which represent 7% of the potential CER imports, both borrowing and banking are prohibited. Borrowing it is also prohibited in Italy, Norway, Poland, Spain, and United Kingdom, representing 37% of the potential CER imports. In the rest of the countries (Austria, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Luxembourg, Netherlands, Portugal, Romania, Slovakia, Slovenia and Sweden), banking and borrowing are allowed.

compliance purposes. CERs generated by nuclear facilities, land use, land use changes, and forestry activities are not permitted.[6]

Both EUAs and CERs are the most important traded assets in the European Union Emissions Trading Scheme (EU-ETS).

2. The ICE ECX

Trading activity in the EU-ETS is fragmented through electronic organized spot and derivative markets and also OTC markets. Each Member State has its own account where the balance of the allowances of each installation is captured. Trading activity, however, is not restricted to the companies affected by the 2003/87/CE Directive. To guarantee additional sources of liquidity, external agents are allowed to trade too. To participate, however, they must have a trading account in the corresponding market. As the European Commission does not preclude each EU member from having its own trading platform, trading of carbon-related assets is fragmented through different markets around Europe.[7] From 2005 to 2007, spot trades of Phase II EUAs were not possible; futures on Phase I and Phase II EUAs, however, were both simultaneously traded.[8]

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[6] In Phase III, these restrictions will increase and, from 2013 onwards, all CERs generated from projects whose objective is the destruction of HFC-23 and N_2O gases cannot be used for compliance objectives. In addition, the scheme allows the Member States to bank (but not borrow) CERs from Phase II to Phase III up to a limit of 2.5% of the EUAs allocated.

[7] Spot markets include BlueNext (Paris), which is part of NYSE-Euronext since December 2007, Energy Exchange of Austria (Vienna), NASDAQ OMX Commodities Europe (Oslo), European Energy Exchange (EEX, Leipzig), European Climate Exchange (ECX, London), only in Phase II, and Gestore Mercato Elettrico (Rome). Future markets on EUAs include European Climate Exchange (ECX, London), NASDAQ OMX Commodities Europe, EEX, and BlueNext only in Phase II. Options on EUAs are also traded in some of the previous markets, such as ECX.

[8] The first spot trade for Phase II EUAs took place in BlueNext on February 28th, 2008. The first spot (future) trade on an organized market on EUAs took place on March 8th, 2005 (February 11th, 2005) in EEX (NASDAQ OMX Commodities Europe).

Among the different platforms, the European Climate Exchange (ECX), in London, is by far the most liquid pan-European platform for carbon emissions trading. ECX is a member of the Climate Exchange Plc group, listed on the AIM market of the London Stock Exchange. ECX futures contracts are operated by the Intercontinental Exchange (ICE) Futures Europe, one of the leading markets in the negotiation of energy derivatives in Europe. Trading on ICE ECX contracts is handled either by the ICE Electronic Platform, for ordinary trades, the Block Trade Facility, for bilateral transactions of large size (minimum 50 lots), or the Exchange of Futures for Physicals/Swaps (EFP and EFS), to transfer an OTC position to an on-exchange futures position. Members of the ICE Futures Europe enabled for ECX contracts can operate on their own account only ('Trade Participant') or also on behalf of their clients ('General Participant'). Trading may also be conducted by a Member’s clients ('order routing') where the access to the ICE Platform is granted by the Member.

The ICE Platform daily session starts with a pre-open period of 15 minutes (from 6:45 a.m. UK local time) during which traders can submit, modify and cancel limit orders, but market orders are not allowed. The limit order book is not displayed during this period, but the market reports tentative allocation prices. The pre-opening period ends with a so-called "opening match", a single call auction, where the opening price and the allocated volume are determined by an algorithm. No new orders are allowed during the opening match.

During the continuous session, from 7:00 a.m. to 5:00 p.m., investors can submit limit orders (default type), which are stored in an electronic limit order book (hereafter LOB) following strict price-time priority criteria, market orders, and block orders. Stop orders were also introduced in January 2008. Limit orders can be modified (in price or volume) or withdrawn from the LOB. By default, standing limit orders expire at the end of a trading session. The contracts are traded in lots. Each lot equals 1,000 tonnes of CO_2 equivalent, that is, 1,000 EUAs. The quotation is in Euros per lot and the minimum tick size for all contracts is €0.01.

As regards transparency, ECX offers real-time prices through the market screens and the major information and data vendors. The LOB is open during the continuous session. All orders entered and the resulting executed trades, however, are anonymous. Iceberg orders are allowed, which means that traders may choose not to display the full size of their limit orders. The unrevealed part of the order is only released when the first part of such order is completely filled. The hidden part of the iceberg order loses time priority.

A trade happens in the ICE Platform when two orders of opposite sign for the same contract and expiry date match. Matching happens when the price of the bid (offer) order equals or is greater (lesser) than the price of the offer (bid). Dynamic price limits computed from the prior transaction price are activated during the continuous session. When these limits are reached, the order that caused the limit hit ceases executing and the remaining volume of the order is cancelled.

Since 2005, ECX has invited Members to act as market makers for the futures contracts on EUAs. However, the first two market makers were announced on July 24th, 2007. The market maker programs extend for periods of three to six (extensible) months, and the positions are limited to a maximum of three to five market makers per contract. Market makers must ensure, on a daily basis, that the spread is not wider than a predetermined amount. For December contracts the minimum spread is either €0.05, €0.08, €0.15 or €0.20 depending on the time the program is announced (it tends to decrease from Phase I to Phase II) and the contract expiry (it is smaller for contracts with close expiry). Market makers must also guarantee a minimum depth of ten lots on both sides of the book, and they must make the market for at least 85% of the duration of the continuous session.

In general, Phase I and Phase II ICE ECX EUA futures are listed on a quarterly expiry cycle, with March, June, September and December contracts up to 2012. The first ICE ECX future contract was issued on April 22nd, 2005, with expiry in December 2005. The contracts are physically delivered by transfer of EUAs. Daily settlement prices are obtained as the trade weighted average of transaction prices during the closing period (4:50 – 5:00 p.m.) as long as a minimum volume is achieved.

Most of the trading activity of the ECX is concentrated in December expiry contracts, the contract with the closest expiry being the most traded one.

3. EUAs and CERs

The evolution of both EUAs and CERs' prices have been affected by two relevant events that occurred in the market, one in each phase. The first one was related to the over-allocation of Phase I EUAs, which collapsed Phase I prices and affected Phase II prices. The second event is the financial crisis, which has dramatically affected economic growth in the countries and, consequently, the prices of the allowances.

The price evolution for EUA futures contracts shows that until April 24th, 2006, futures prices had a positive trend, surpassing the price of 30 Euros per contract, but continuous rumors of over-allocation caused Phase I prices to crash, negatively affecting Phase II prices as well. Before April 24th, 2006, the futures prices for Phase I EUAs and Phase II EUAs were quite close.

Phase I was finally characterized by an over-allocation of EUAs which inevitably resulted in a dramatic fall in prices. Between April 25th and April 27th, The Netherlands, The Czech Republic, and France, all declared a surplus of EUAs, while Spain was less short than expected. As a consequence, rumors of over-allocation rose. From that date on, the spread between Phase I and Phase II future prices progressively increased. At the end of 2006, the Phase I futures price was €6.60, while the Phase II futures price remained close to €20. In general, the 2006 total emissions surpassed those of 2005, but many EU Members were still long in allowances. Rumors of over-allocation continued and prices experienced a definitive drop. On May 14th, 2007, eight months before their expiry date, the price of a December 2007 futures contract on Phase I EUAs was below €0.33. From that date, the Phase II EUA futures price started a progressive increase, achieving its maximum on July 2008. The appreciation of the Phase II EUAs is the result of the approval by the European Commission of more conservative NAPs for Phase II. Determined to avoid history repeating itself, the European Commission imposed severe cuts on the Members' initial proposals. Moreover, the price of crude oil was steadily increasing by that time.

Phase II prices were drastically affected by the international crisis and the consequent downward revision in the real production expectations, directly connected with the expected CO_2 emissions. On February 12nd, 2009, the EUA December 2012 futures price reached a minimum of €9.43. From February 2009 to December 2010 the futures price of the EUA fluctuated around €15 per tonne, then started to increase again until its peak of €18.27 during May 2011. In June 2011 prices once again began to decline until December 2011, achieving a minimum price of €7.32 on the last trading day of the month.

CERs started trading in the ICE ECX platform in March 2008. Since then, prices have been very close to EUAs, but always below, maintaining a positive spread that has diminished over time, reaching its minimum during February 2009. In general, the behavior has been very similar to EUAs, as these two assets share a common trend.

Concerning the trading activity, it should not come as a surprise that trading activity increased from the December 2005 futures to the December 2012 futures, from Phase I to Phase II contracts in general, and that the December 2007 futures experiences the lowest price and highest standard deviation of transaction prices. Additionally, regular screen-based trades are by far the most extensive, however, in terms of volume traded their weight decreases, suggesting that the average size of screen trades is smaller than that of other less ordinary trades.

In general, the number of trades for EUA contracts exceeds by far the number of trades for CER contracts; however, CER volume per trade is twice the EUA volume for both December 2008 and 2009 contracts, similar for both December 2010 and 2011 contracts, and half the volume for both December 2013 and 2014 contracts. Finally, it is remarkable that although the database finishes in 2011, the CER December 2012 contract is the most traded one (and not the December 2011 contract), highlighting the importance the end of Phase II has on CERs contracts.

4. Dissertation structure

This PhD dissertation is structured in four different chapters. It focuses on the study of statistical properties and market microstructure features of the most frequently traded emission credits traded in the European carbon market, EUAs and CERs. This dissertation aims to: (a) shed light on the empirical properties of EUA returns; (b) determine the best rollover criterion to generate long EUA and CER price series and EUA and CER time series; (c) analyze the evolution through time of the quality of the ICE ECX market, and (d) model and evaluate the existence of information-motivated trading in the European carbon market.

The structure of the PhD dissertation is as follows:

- Chapter I: Is the EUA a new asset class?
- Chapter II: Rolling over EUAs and CERs.
- Chapter III: The Timeline of Trading Frictions in the European Carbon Market.
- Chapter IV: Modeling the Probability of Informed Trading in the European Carbon Market.

Chapter I was motivated by the necessity of clarifying the statistical behavior of a new asset, the EUA. In our analysis, we aim to discern from an empirical point of view whether it performs as a financial asset, a commodity, or another kind of asset. Our main conclusion is that the European Union Allowances do not behave like common commodities or financial assets, and they should be considered as a new asset class.

Chapter II tests whether or not the election of a rollover criterion affects the results of a carbon market analysis. In the carbon market, futures contracts are the most relevant assets. Both researchers and traders link different futures contracts in order to get a unique time series. We test different methods for rolling over futures contracts and look for significant differences between the different criteria. Our results show that in general the election of the rollover criterion does not affect the results of the analysis, so the simplest methodology (the last day criterion) seems to be the suitable.

Chapter III provides a complete analysis of the microstructure of the carbon market, studying in depth the trading frictions of the market and the quality of prices. Our results show that in general the liquidity of the market has increased over time, mainly from Phase I to Phase II, although market quality during Phase II has been recovering from the market breakdown at the end of Phase I and the international financial crisis, and by the end of 2010 this recovery process had not yet finished.

Chapter IV provides evidence on the use of private information in the European carbon market. We study if the actual structure of the market allows the companies to use private information and take advantage of it. Our conclusions prove the existence of informed trading before the verified emissions reports are made public and give an increasing importance to CERs during 2011.

5. The data

Both EUAs and CERs can be traded in several organized markets such as spot, futures and options markets. From among these markets, most of the trading volume is concentrated in the futures markets, especially in the futures contracts listed for electronic trading at the European Climate Exchange (ECX), with maturity in December of each year. For this reason, we have chosen the futures prices with delivery in December in order to obtain the most informative prices for EUAs and CERs.

Our database is basically composed of daily and high-frequency data from the ICE ECX platform for all December futures contracts with maturities between 2005 and 2014, for both EUAs and CERs. For each day, the daily database contains the open, high, low and settlement prices (in Euros), the total volume (in lots) and the open interest (in lots). Regarding the high-frequency data, we have a unique dataset about transactions. For each trade, we have the time stamp (to the nearest hundredth of a second), the price (in Euros), the volume (in lots), the sign (i.e., whether it is buyer- or seller-initiated) and the trade type. In our different analysis, we focus only on screen (ordinary) trades, these being the most extended and popular type of trades. During the first two Chapters of the dissertation, we only use daily data from the ICE ECX platform, while in the third and fourth chapters we use high-frequency data from the ICE ECX platform.

In particular, in Chapter I we have focused on daily data from December 2008, 2009 and 2010 EUAs futures contracts. In order to carry out our study, we will study the EUA returns of these contracts from April 2005 to December 2010. The period sample goes from April 22th, 2005 to December 15th, 2008 for the first contract; from April 22th, 2005 to December 14th, 2009 for the second one, and from April 22nd, 2005 to December 20th, 2010 for the third one, collecting 936, 1,190 and 1,446 daily returns for 2008, 2009 and 2010 EUA ECX futures contracts, respectively. We limited the analysis to Phase II data, as Phase I was a pilot phase dramatically affected by an over-allocation which inevitably altered Phase I EUA prices, provoking a sharp decline in prices and leaving them at around zero at the end of 2007.

The Chapter II database consists of all the available daily data for both EUAs and CERs December futures contracts with maturities between 2005 and 2012, and the contract with maturity in March 2008, from their start (April 22nd, 2005, and March 14th, 2008, for the EUA and CER futures contracts, respectively) to December 30th, 2011.[9] Additionally, and in order to obtain information related to the number of transactions, we have also employed all the intraday data available, for all the futures contracts used in the chapter.

In Chapter III, we employ high frequency data provided by the ICE ECX platform covering all of Phase I (from April 22nd, 2005 to December 17th, 2007) and part of Phase II (from April 22nd, 2005 until December 31st, 2010) of the EU-ETS. The data set covers all EUA December contracts with maturities between 2005 and 2010. In order to obtain a single time series for each Phase, we roll over the different December contracts, for each Phase, through the "maximum volume criterion". According to this criterion, we switch contracts when the front contract is no longer the most systematically negotiated. The resulting Phase I time series covers from April 22nd, 2005 to December 17th, 2007, while Phase II time series goes from June 17th, 2005 to December 31st, 2010.

In the last chapter of this dissertation (Chapter IV) we use high frequency and daily data obtained from the ICE ECX Platform, covering the period from March 14th, 2008, the day CERs began to quote in ECX, to December 31st, 2011. We focus on trade data for all December futures contracts with maturities between 2008 and 2014, for both EUAs and CERs. As the methodology employed in Chapter IV requires the use of continuous time series and futures contracts have a finite life, we generate single time series by rolling over contracts using the "last day criterion". This criterion switches from one contract to another on the expiry date of the first one. For our analysis, we considered three rollover series for each asset (EUAs and CERs): the front contract, the second nearest delivery contract, and the third nearest delivery contract.

[9] As an exception, in this chapter we have employed an additional maturity (March 2008) from the usual December contracts, because of this contract being the last Phase I futures contract traded in the market.

All time series used in the dissertation have been corrected for reporting errors, confirmed by ECX staff members. In computing return series, overnight returns are also eliminated. Returns are calculated using trade prices in logs.

6. Summary of the chapters

The thesis dissertation has covered different aspects of the European carbon market, highlighting its statistical properties and market microstructure. In particular, the thesis is composed of four chapters: Chapter I studies the empirical properties of Phase II EUAs returns; Chapter II analyzes the different rollover criteria applied to both EUAs and CERs; Chapter III evaluates the impact of the market collapse at the end of Phase I and the posterior financial crisis on the quality of the European carbon market, and Chapter IV provides evidence of informed trading in the European carbon market.

Chapter I: ***Is the EUA a new asset class?*** The listing of a new asset requires the knowledge of its statistical properties prior to its use for hedging, speculative or risk management purposes. In this paper, we study the stylized facts of European Union Allowances (EUAs) returns. The majority of the phenomena observed, such as heavy tails, volatility clustering, asymmetric volatility and the presence of a high number of outliers are similar to those observed in both commodity futures and financial assets. However, properties such as negative asymmetry, positive correlation with stocks indexes and higher volatility levels during the trading session, typical of financial assets, and the existence of inflation hedge and positive correlation with bonds, typical of commodity futures, are also detected. Therefore, our results indicate that EUAs returns do not behave like common commodity futures or financial assets, and point to the fact that EUAs are a new asset class.

A first version of this chapter was written during the last year of my Quantitative Finance Master's degree. The first version of the chapter was presented at the VII Workshop in Banking and Quantitative Finance (Spain, July 2009), organized by the University of Basque Country. Preliminary versions of the first chapter were accepted to present at the 8th Annual International Conference on Business (Greece, July 2010), organized by the Athens Institute for Education and Research, the XII Workshop on Quantitative Finance (Italy, January 2011), organized by the University of Padua, and the 8th International Conference on the European Energy Market (Croatia, May 2011), organized by the University of Zagreb. The chapter has been published in a preliminary version as Working Paper (WP-AD 2012-14) by Instituto Valenciano de Investigaciones Económicas (IVIE). The final version was submitted to the *Quantitative Finance* in April 2010 and was finally accepted in April 2012.

Chapter II: ***Rolling over EUAs and CERs***. Whatever derivative contract has a finite life limited by its maturity. The construction of long series, however, is of interest for academic, hedging and investments purposes. In this study, we analyze the relevance of the choice of the rollover date on European Union Allowances (EUAs) and Certified Emissions Reduction (CERs) futures contracts. We have used five different methodologies to construct long series and the results show that, regardless of the criterion applied, there are not significant differences between the resultant return distribution series. Therefore, the least complex method, which is to roll over on the last trading day, can be used in order to reach the same conclusions. Additional liquidity analysis confirms this method as the optimum method to link EUAs and CERs series, indicating that simplicity when linking EUAs and CERs series is not at odds with liquidity.

The chapter was presented at the III Workshop on Energy Markets and CO_2 markets (February 2012, Spain), organized by the Cátedra Banco Santander - University of Valencia, and at the 9th International Conference on the European Energy Market (May 2012, Italy), organized by the European University Institute of Florence. The chapter has been published as a Working Paper by IVIE (WP-AD 2012-15). The final version is under review at this moment in an international journal.

Chapter III: ***The timeline of trading frictions in the European carbon market***. The release of verified CO_2 emissions and compliance information for 2005 by the European Commission in May 2006 and the continued rumors of over-allocation of emission allowances (EUAs), resulted in an early collapse of the European Carbon Market, with EUA prices about zero by September 2007. We show that this market breakdown and the subsequent outbreak of the international financial crisis have had a persistent effect on the quality of prices of the most active derivatives market for carbon dioxide emissions. We report substantial improvements in terms of liquidity, adverse selection costs, and friction-related volatility from Phase I to Phase II. However, price quality (the proportion of friction-unrelated price return volatility) during the period 2008-2010 has been below the levels achieved before the 2007 collapse. Our findings suggest that the carbon market has not fully recovered from the negative effects of its 2007 breakdown and the subsequent financial crisis.

The chapter was initiated during my stay at the University of the Balearic Islands. This paper was presented at the 9th International Conference on the European Energy Market (May 2012, Italy), organized by the European University Institute of Florence, and at the 10th INFINITI Conference on International Finance 2012 (June 2012, Ireland), organized by the Trinity College Dublin. The Chapter has been published as a Working Paper by IVIE (WP-AD 2012-05). The final version is under review in an international journal at this moment.

Chapter IV: ***Modeling the probability of informed trading in the European carbon market***. We provide evidence of informed trading in the European carbon market. We adapt Easley et al.'s (1996) PIN methodology to the particularities of this market by isolating the trading activity on the two carbon offsets: European Union Allowances (EUAs) and Certified Emission Reductions (CERs). We find that the PIN regularly increases before the publication of the yearly verified-emission reports. CERs exhibit lower average PIN than EUAs. While the PIN of CERs has increased over time, together with its share in total trading activity, EUAs' PIN has remained pretty stable. Our findings suggest that CERs must not be avoided in any decision or analysis made by researchers, regulators or traders interested in the European carbon market.

Chapter IV was elaborated during my research visit to the Johnson Graduate School of Management of Cornell University (New York, USA) under the supervision of Professor Gideon Saar, Dr. Philip and Rosalyn Baron Professor of Management and associate professor of Finance. This paper was presented in the 4th International IFABS Conference on Rethinking Banking and Finance: Money, Markets and Models (June 2012, Spain), organized by the University of Valencia.

7. Stays, grants and prizes

I developed my PhD dissertation thesis in three different universities:

- The University of Valencia (Department of Financial Economics, Valencia, Spain), as a PhD student from the university.

- The University of the Balearic Islands (Department of Business, Mallorca, Spain), during a stay from May 1st, 2010 to July 31st, 2010.
- The Johnson Graduate School of Management - Cornell University (Ithaca, New York, USA), during a stay from September 1st, 2011 to February 29th, 2012.

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- A F.P.U. (*Formación del Profesorado Universitario*) Grant from the Ministry of Education (Spain), during the period July 16th, 2007 - July 15th, 2012.
- Two Mobility Grants from the Ministry of Education (Spain), one for each stay.
- A Scholar Fellowship during my stay at Cornell University.
- A Mobility Grant for official master's degree from the Ministry of Education (Spain), during the master's degree period.

Finally, I received an academic award for the second best student, after I finished my master's degree.

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Chapter I

Is the EUA a new asset class?

1. Introduction

In order to achieve the reduction objectives for greenhouse gases emissions, the European Union decided that a big part of that reduction would have to be directly assumed by the companies of the most polluting sectors. Since 2005, the companies of these sectors, included in the 2003/87/CE Directive, receive each year entitlements to emit one tonne of carbon dioxide equivalent gas, which are denominated European Union Allowances (EUAs).[1] At the end of the control period, the firms covered by the environmental regulations have to give a sufficient number of allowances to cover their verified real emissions. If these companies emit more CO_2 than the allowances they own, they would have to go to the European Union Emission Trading Scheme (EU ETS) and buy the difference. It is important to highlight that not only the polluting companies participate in the EU ETS, but also external agents can trade in it. Therefore, knowledge of the statistical properties of EUAs is of interest not only for hedging operations, but also for speculative or risk management purposes.

In spite of the youth of the EU ETS, the academic literature has analyzed the CO_2 market from diverse perspectives. Mansanet-Bataller and Pardo (2008) study the market at an institutional level. Miclaus et al. (2008), Daskalakis and Markellos (2008), Daskalakis et al. (2009) and Mansanet-Bataller and Pardo (2009) study different aspects of the market efficiency. Benz and Hengelbrock (2008), Rotfuss (2009), Rittler (2012) and Uhrig-Homburg and Wagner (2009) analyzed the lead-lag relationship between the spot and futures markets, this last one being the market that leads the price discovery process. Finally, Borak et al. (2006), Chesney and Taschini (2012), Benz and Trück

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[1] The sectors included in the 2003/87/CE Directive are: energy (electricity, co-generation), refining petroleum, iron and steel industry, mineral products, cement, lime, glass, ceramics (roofing tiles, bricks, floor tiles, etc.), cardboard, pulp and paper.

(2009) and Daskalakis et al. (2009) proposed different alternatives to model the price dynamics of CO_2 emission allowances.[2]

The papers mentioned above analyze short periods of time and the statistical properties of EUA returns appear as a secondary objective. This is precisely the main purpose of our study. Specifically, starting from the stylized facts described by Cont (2001) for financial assets, and from the statistical properties analyzed by Gorton and Rouwenhorst (2006) and Gorton et al. (2012) for commodities, we study the stylized empirical facts of EUA returns. By doing so, we will determine whether EUA behaves like a financial asset, a commodity, or a new asset. The knowledge of its statistical properties is of interest for both policy makers and portfolio managers, in terms of regulation and portfolio diversification, respectively. The remainder of the paper is organized as follows. Section 2 presents the stylized facts observed in assets grouped into four categories. Section 3 describes the data we used in the study. The results of the analysis are presented and discussed in section 4. The last section summarizes with some concluding remarks.

2. Stylized facts of asset returns

Following Cont (2001, p. 233), we define the stylized facts of an asset as a set of statistical facts which emerge from the empirical study of asset returns and which are common to a large set of assets and markets. Some papers have overviewed the stylized facts that are characteristics of the financial assets (see among others, Pagan (1996), Cont (2001), Morone (2008), and Sewell (2011)) and those that are common in the commodities (see Gorton and Rouwenhorst (2006) and Gorton et al. (2012)). Although some stylized facts are related to each other, the statistical characteristics of assets

[2] An excellent review of this kind of literature can be found in Convery (2009).

returns can be grouped into four large sets of phenomena that have to do with the distribution of returns, correlation facts, volatility-related properties and commodity-related facts.

In the first group, the characteristics observed in the historical returns distribution are analyzed. The first step is to look into the existence of normality in the distribution of returns. In the case of not rejecting normality, we could not reject both symmetry and the absence of heavy tails. However, the rejection of the hypothesis of normality would make necessary a more exhaustive analysis to determine if the reason for the rejection comes from the existence of asymmetry or because the frequency curve is more or less peaked than the mesokurtic curve. The second aspect we analyze is the *intermittency* which refers to the phenomenon that returns present, at any time scale, high variability that is translated in the appearance of *outliers* throughout the asset life.[3] Thirdly, we investigate the *aggregational gaussianity,* a third aspect that is detected in historical returns distribution and which makes reference to the fact that the aggregation of data in bigger time intervals approaches the Gaussian data distribution. While the two last phenomena have been observed both in financial assets and commodity futures, the empirical evidence regarding asymmetry usually indicates that the skewness is negative in financial assets and positive in commodities. Finally, we have analyzed if EUA returns are stationary. When series are non-stationary and follow a unit root process, persistence of shocks will be infinite. If EUA prices follow a trend stationary process, then there exists a tendency for the price level to return to its trend path over time and investors may be able to forecast future returns by using information on past EUA returns. However, the majority of economic and financial time series exhibit trending behavior or non-stationarity in the mean. If EUA price series were non-stationary, any

[3] Outliers refer to those returns which, by their magnitude, are considered as unusual and infrequent.

shock to EUA price would be permanent, implying that EUA future returns would be unpredictable based on historical observations.

The second group refers to some correlation facts observed in the returns of whatever asset and to their consequences. Firstly, we study the autocorrelation of the returns. This has been the classical way to test the weak form of the efficient hypothesis in financial markets. The absence of significant linear correlations in returns has been widely documented and it is usually not detected except for very small intraday time scales. Secondly, given that the correlation test may be influenced by the presence of extreme returns, we carry out a run test in order to check the existence of randomness in EUA returns generation. With this test, we get robustness on a possible predictability of EUA returns over the short term. Thirdly, we analyze the presence of a slow decay of autocorrelation in absolute returns, also known as the *Taylor effect*. Following Taylor (2007), this effect makes reference to the fact that a big return in absolute terms is more probably followed by another big one, rather than a small one. This phenomenon, unlike the two previous ones, is interpreted as a sign of long-range dependence.

The third group of facts investigates the specific characteristics observed in volatility. The first well-known property about volatility is the positive autocorrelation observed in different measures of volatility over several days. This fact is generally detected through the existence of autocorrelation in squared returns and it is known as *volatility clustering*. Secondly, we study three volatility-related cross-correlation facts. The first one looks at whether volatility responds differently to positive and negative shocks of the same magnitude, the second one analyzes the correlation between volume and volatility, and the last one examines the correlation between the change in the open interest and the volatility.[4] Although studies on the relationship between trading measures and the underlying price volatility provide mixed evidence, following Bhargava and Malhotra (2007) a number of other researchers report a positive correlation between trading activity and volatility. The significance of these two relationships would indicate that the volume and/or the change in the open interest, in EUA markets, could be used as explanatory variables of volatility.

The last group alludes to specific features extracted from commodities behaviors. The first aspect we investigate is the presence of a non-trading effect observed in the volatility of weather sensitive assets. Following Fleming et al. (2006), trading versus non-trading period variance ratios in weather-sensitive markets are lower than those in the equity markets. Given that Mansanet-Bataller et al. (2007) and Alberola et al. (2008) have showed empirical evidence about the influence of weather on carbon returns, we study the non-trading effect on EUAs by testing whether the information flow on EUA markets is evenly distributed around the clock. Another stylized fact characteristic of commodities is the negative correlation with stocks and bonds. Generally, commodity futures exhibit certain negative correlation, mainly in the early part of falling periods, as is noted in Gorton and Rouwenhorst (2006). Furthermore, the negative correlation becomes greater as we increase the time lag in which we hold the positions. Finally, we test the property of *inflation hedge*. Assets hedge against inflation when they correlate positive and significantly against it. Following Gorton and Rouwenhorst (2006), commodity futures usually show better behavior against unexpected inflation, than stocks or bonds do, and therefore, they can be used for this kind of hedging.

[4] Open interest is the total sum of all outstanding long and short positions of futures contracts that have not been closed.

3. The data

To carry out the analysis of the stylized facts of EUA returns, we have to select the most representative EUA asset in the market and the time frame. EUAs can be traded in several organized markets such as spot, futures and options markets. From among these markets, most of the trading volume is concentrated in the futures markets, especially in the futures contracts listed for electronic trading at the European Climate Exchange (ECX).[5] Furthermore, empirical evidence cited in section 1 supports the notion that the price discovery process is led by the futures markets. For these reasons, we have chosen the futures prices in order to obtain the most informative EUA return.

Related to the time frame used in this study, it is convenient to clarify some aspects of the EU ETS. The trading on EUAs has been organized into different phases. Phase I covered the years from 2005 to 2007 and was considered as a *pilot* or *learning* phase, characterized by an excess of EUAs that provoked a sharp decline in prices.[6] Phase II matches the Kyoto protocol fulfillment period which goes from January 2008 to December 2012, while Phase III will include the period 2013 to 2020.[7] Another important aspect to consider is that Phase I EUAs could not be used in Phase II, meaning that *banking* was not allowed between Phase I and Phase II. Nevertheless,

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[5] The unit of trading of one contract is one lot of 1,000 CO_2 EU Allowances. See the User Guide of ICE ECX Contracts: EUAs and CERs at the https://www.theice.com/productguide/ProductGroupHierarchy.shtml?groupDetail=&group.groupId=19 for further information about the contract specifications of ECX EUA futures contract (last accessed on March 20, 2012).

[6] The special features observed in this period are treated in detail by, among others, Miclaus et al. (2008), Paolella and Taschini (2008), Mansanet-Bataller and Pardo (2009), Benz and Trück (2009), and Daskalakis et al. (2009).

[7] Given that the EU ETS is organized in Phases, the Member States must elaborate a National Allocation Plan (NAP) for the first two Phases, in which the Member States attribute their emission allowances to the different companies, included in the sectors involved in the 2003/87/CE Directive, and establish the emission limits for the different sectors, as well as for each one of the facilities covered by EU ETS. Therefore, these NAPs establish the EUA supply available in the market until 2012. Contrary to Phase I and Phase II, in Phase III, only one EU-wide emissions allocation under ETS Phase III will be elaborated, where each installation's individual allocation will be decided by the European Commission.

banking is allowed between Phase II and Phase III, a reason why Phase II EUAs might be used during the 2013 to 2020 period. For these reasons, we limit our sample to Phase II EUA futures returns. In particular, we focus on 2008, 2009 and 2010 EUA ECX futures contracts. The period sample goes from April 22nd, 2005 to December 15th, 2008 for the first contract; from April 22nd, 2005 to December 14th, 2009 for the second one, and from April 22nd, 2005 to December 20th, 2010 for the third one, collecting 936, 1,190 and 1,446 daily returns for 2008, 2009 and 2010 EUA ECX futures contracts, respectively. Figure 1 shows the price evolution for the three EUA futures contracts. In general, all three contracts share a common behavior. Until April 24, 2006, future prices had a positive trend, over-passing the 30 Euros price per contract, but continuous rumours of over-allocation crashed Phase I prices, affecting negatively Phase II prices too. From then, prices declined until it reached its first minimum of 14 Euros in February 2007. In July 2008, EUA prices approached their maximum quote of over 30 Euros, following which prices started a new bearish period because of the financial crisis. By February 2009, EUA prices reached their historical minimum around 8 Euros. Finally, from April 2009 to the end of 2010, EUA prices have been fluctuating around 14 Euros.

Additionally, in order to test some correlation facts, other series of data have been used: a stock index, a stock index future contract, bond futures contracts, a commodity future contract, a risk free asset series and the observed inflation. We have chosen for all of these series the European benchmarks, using the same time frame as the one we have selected for each EUA contract. Specifically, we have chosen the Euro Stoxx 50 and its futures contract, traded at the EUREX market, as indicative of a European stock index and its future. Regarding interest rates, the fixed income futures have been also obtained from the EUREX market. The three references chosen for this case are the Euro Schatz futures, the Euro Bolb future, and the Euro Bund future, as benchmarks for European short-, mid- and long-term bonds prices, respectively. As a representative commodity futures contract, we have chosen the Brent futures contract traded at International Petroleum Exchange (IPE). The risk free asset has been approached through the 1-month Euribor rate and, as a proxy of the inflation rate, we have used the European Harmonized Index of Consumer Prices (HICPs).

We have carried out our study using returns defined as $r_t = log\left(p_t / p_{t-1}\right)$, where p_t is the closing price of the futures contract on day *t*. Finally, when it has been needed, we have switched futures contracts on the last trading day in order to create a continuous series in futures contracts.

4. Results

In this section, we test the presence of the stylized facts described in section 2: the distribution of returns, correlation facts, volatility-related features and commodity-related facts. For each case, we present the methodology used to test the empirical property, the results and the financial implications.

4.1. Data distribution

From a financial point of view, the *gaussianity* of returns data is of interest for portfolio theory, derivatives pricing and risk management. However, one of the most well-known properties in the distributions of assets returns is precisely the non-normality of the return series and the fact that they present a greater number of extreme values than those observed in series with Gaussian distributions.[8] As a background, Table I presents the summary statistics of the EUA returns for 2008, 2009 and 2010

[8] In Catalán and Trívez (2007), some reasons concerning the importance of extreme values are presented.

futures contracts, and Figures 2a, 2b and 2c show the histogram of the historical daily return distribution. All three daily series are leptokurtic and present negative skewness. The Jarque-Bera statistic rejects the null hypothesis of normality for all three series at the 5% level. The histogram shows heavy tails and a high number of extreme returns, both positive and negative ones.

The Jarque-Bera statistic is based on the assumption of normality; therefore the daily return series can be symmetric but non-normal due to the excess of kurtosis. To check this fact, we test the distribution symmetry by applying the method proposed by Peiró (2004). Firstly, we divide each sample into two subsamples, where the first subsample contains the excesses of positive returns with respect to the mean $r^{+} = \left\{ r_t - \bar{r} \middle| r_t > \bar{r} \right\}$, and the second one, the excesses of negative returns with respect to the mean, in absolute terms $r^{-} = \left\{ \bar{r} - r_t \middle| r_t < \bar{r} \right\}$. Secondly, we use the Wilcoxon rank test to check whether the two subsamples come from the same distribution.

Given the negative skewness coefficients reported in Table I, the asymmetry tests, non-reported, show a statistic of 2.9854 (p-value 0.0028) for the future with maturity in 2008, 2.0044 (p-value 0.0450) for the 2009 future and 1.8161 (p-value 0.0694) for the 2010 future. Therefore, we observe a significant negative asymmetry for the first two contracts, something common in financial assets such as stocks, while we cannot reject symmetry at the 5% level for the 2010 future. This characteristic has a direct implication in margins requirements asked by clearing houses in EUA derivatives markets. A negative asymmetry implies more risk for long positions and, as a consequence, bigger margins should be asked for those positions.

The second aspect we have analyzed is the *intermittency* of the series. To study the existence of this empirical fact, we have used the VaR approach and, following

Galai et al. (2008), the procedure based on the calculation of the Huber M-estimator to distinguish between outliers and the body of the distribution. Table II presents the outlier detection based on daily returns for the EUA 2008, 2009 and 2010 futures contracts. 5% VaR (95% VaR) provides the outlier detection through the Value at Risk method, considering as extreme positive (negative) outliers those returns which are over (under) the 5% 1-day VaR (the 95% 1-day VaR).[9] The 5% 1-day VaR measure (3.89%, 3.98% and 3.78% for 2008, 2009 and 2010 futures, respectively) is of interest for estimating the risk of loss in short positions in futures markets, while the 95% 1-day VaR (4.53%, 4.56% and 4.24% for 2008, 2009 and 2010 futures, respectively) is relevant for measuring the same risk but for long positions. Obviously, the number of positive and negative extreme returns is the same, but the 95% VaR measure in absolute terms is higher than the 5% VaR measure, confirming the negative asymmetry previously observed.

To get robustness in the outlier detection analysis, we have obtained the Huber M-estimator. The fifth, ninth and thirteenth columns in Table II present the results following this procedure.[10] Based on the M-estimator, over 17% of returns in all three samples are classified as outliers. Furthermore, in all three samples, the number of negative outliers (90, 110 and 126, respectively) far exceeds the number of positive ones (66, 89 and 105, respectively). Note that in both cases the number of outliers has increased over time.

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[9] Malevergne and Sornette (2004) summarize the virtues of VaR measures in three characteristics: simplicity, relevance in addressing the ubiquitous large risks often inadequately accounted for by the standard volatility, and their prominent role in the recommendations of the international banking authorities.

[10] To obtain outliers by applying the M-Huber estimator, it is necessary to transform the data until the convergence is attained. Furthermore, for the generation of the M-Huber estimator, we have to define the term k which will be used as a limit during the detection of outliers. Following Galai et al. (2008), we have chosen k = 2.496. With this selection, the iterative process ends with an M-Huber estimator of 0.000879 for the 2008 future, 0.000561 for the 2009 future and 0.000465 for the 2010 future. A detailed description of this procedure could be found in Hoaglin et al. (1983, chapter 11).

Panel B of Table II presents the size of events measured in the number of standard deviations (σ) that an outlier return deviates from the mean. Independently of the approach, the majority of the outliers have a size between one to four standard deviations. This could be considered as usual for normal distributions. However, the empirical VaR and the Huber M-estimator approaches also detect diverse extreme large movements, in all three futures contracts, that diverge from the mean and the median, respectively, from five to eleven σs. Additionally, Panel C of Table II presents the clusters of outliers. The Huber M-estimator shows concentrations of up to six consecutive outliers while the VaR approach detects clusters of up to three outliers. It is important to note that the number of clusters with this procedure is higher when the outliers are considered independently of their sign, indicating that extreme returns are followed by themselves. On the whole, the results of Table II indicate a high probability of occurrence of large movements in the EUA market and prove the existence of *intermittency* in EUA returns.

Thirdly, we have studied another aspect that is usually detected in historical returns distribution, which is the fact that the aggregation of data in bigger time intervals approaches a Gaussian data distribution. In order to test the *aggregational gaussianity*, we have generated two subsamples both with weekly and monthly returns. The weekly returns have been calculated taking the close price from Monday close to the following Monday close, while the monthly returns takes the closing prices of the last trading day of two consecutive months. Table I presents the statistics for all three subsamples. Given the absence of normality, we have applied the non-parametric Kolmogorov-Smirnov test. Moving from daily returns to lower frequency returns, the normality of the distributions cannot be rejected at the conventional levels of significance. To confirm our results, we have generated two additional subsamples. In the case of weekly returns from Wednesday closing to the following Wednesday closing and for monthly returns calculating returns from two consecutive mid-months days, for all three futures contracts. We obtain similar results, presented in Table I, that confirm the fact that the empirical distribution of EUA returns tends to normality as the frequency of observation decreases.

Finally, we have analyzed if EUA returns are stationary by applying the Kwiatkowski et al.'s (1992) unit root test. We have tested the null of stationarity with intercept and deterministic time trend for the price series in levels. The critical value (at the 1% level) is 0.216 (see Table 1 in Kwiatkowski et al.'s paper, p. 166). If rejected, we have then tested the null of stationarity plus intercept for the time series in first differences. The results indicate that EUA prices should first be differenced to render the data stationary in all three contracts analyzed (see Table III). Therefore EUA prices are difference-stationary and EUA future returns would be unpredictable based on past observations. This fact should be taken into account for cointegration analysis.

4.2. Correlation facts

The second group of empirical aspects is related to some correlation facts observed in the returns and to their consequences. On the one hand, we study the significance of the autocorrelation coefficients. The study of the presence/absence of autocorrelation is a typical way to detect *short-term predictability of returns* from past information. Given the non-normality of daily distributions, we have decided to apply the non-parametric Spearman's ranks correlation coefficient. Table IV presents the Spearman's autocorrelation coefficients and their p-value associated. Autocorrelation is significant and positive only for the first lag at the 1% level.

Note that the square of the autocorrelation coefficient could be interpreted as the fraction of the variation of return on day *t* explained by a lagged return in simple linear regression. In the case of one lagged, the variation of today's return is $(0.124)^2$=1.53%, $(0.109)^2$=1.10% and $(0.0779)^2$=0.61% for 2008, 2009 and 2010 futures contracts, respectively. Therefore, although the influence of the past return is positive and significant, the short-term predictability is very weak. Additionally, and given that there exist a large number of outliers, we have eliminated their effects in the autocorrelation analysis by applying a run test. This test assumes an ordered sequence of n_1 returns above the median and n_2 returns below the median. A run of type 1 (type 2) is defined as a sequence of one or more returns above (below) the median which are followed and preceded by returns below (above) the median. r_1 and r_2 are the number of runs of type 1 and 2, respectively, and r is the total number of observed runs. By comparing the observed number of runs and the expected number of runs, we test the hypothesis that returns follow a random sequence. Too few or too many runs would suggest non-randomness in the distribution. Table V shows the results that indicate that the null of randomness is rejected at the 5% level, for 2008 futures but not for 2009 and 2010 futures contracts. In summary, correlation analysis and run tests indicate a positive but weak short-run predictability of past returns. Furthermore, this small predictability has diminished over time.

Finally, we analyze the presence of a slow decay of autocorrelation in absolute returns, also known as the *Taylor effect*, which would indicate that large returns in absolute terms are more probably followed by another large return, rather than a small one. Note that we have already obtained preliminary evidence of dependence among outliers; however, the *Taylor effect* makes reference to a feature that is present in the entire sample. To test this effect, we have obtained the Spearman's ranks autocorrelation coefficient taking into account absolute returns. Table VI presents the results that indicate a significant slow decay of sample autocorrelation coefficients at the 5% level, suggesting a long-range dependence in absolute returns.

4.3. *Volatility-related features*

The third group of facts investigates some aspects of EUA returns related to some phenomena of the time series volatility. The first one is related to the positive autocorrelation observed in different measures of volatility; the second one makes reference to the fact that volatility responds differently to positive and negative shocks of the same magnitude; and the last one analyzes the correlation between trading-related measures and volatility.

Firstly, we have depicted the squared returns of all three futures contracts as a standard approach to detect volatility clusters. Figures 3a, 3c and 3e exhibit this fact, that is very common both in financial and commodities assets series.

Additionally, we have obtained a high-low daily volatility measure. We have chosen the volatility measure proposed by Garman and Klass (1980) due to its higher relative efficiency than the standard estimators. The Garman and Klass volatility measure (hereafter Garman-Klass volatility) is obtained in the following way:

$$\sigma_{GK} = 0.511(u-d)^2 - 0.019\{c(u+d) - 2ud\} - 0.383c^2$$

where O_t = today's opening price; H_t = today's high price; L_t = today's low price; C_t = today's close price; $u = \log H_t - \log O_t$ is the normalized high; $d = \log L_t - \log O_t$ is the normalized low; and $c = \log C_t - \log O_t$ is the normalized close.

Figures 3b, 3d and 3f represent the evolution of the Garman-Klass volatility over the trading days of all three futures. Both figures show *volatility clustering*. There are two striking clusters in July 2005 and April 2006. Benz and Hengelbrock (2008) relate the first one to unexpected selling by some Eastern European countries and to the insecurity perceived in the market as a consequence of the terrorist attacks in London in July 2005. The second cluster took place in April 2006 and is explained by the fact that in April 2006 the market understood that there was a great excess of allowances in Phase I, that also affected Phase II EUA futures.

Panel A of Table VII presents the positive and significant Spearman's cross autocorrelation coefficients of Garman-Klass volatility for the first ten lags. The results confirm the existence of volatility clusters that decay very slowly.

Secondly, we study the *asymmetric volatility*, which is the fact that volatility responds differently to positive and negative shocks of the same magnitude.[11] Cont (2001), Bouchaud et al. (2007) and Bouchaud and Potters (2001) comment on the existence of a negative correlation between volatility and returns in financial assets, and particularly in stocks, which tends to zero as we increase the time lag. Panel B in Table VII present the Spearman's cross correlation coefficients between Garman-Klass volatility and returns. Both the contemporaneous and the one-period lagged correlation coefficient are significant and negative at the 1% level, confirming that EUA volatility responds differently to positive and negative returns.

Although volatility modeling is not an objective of this study, to get additional insights about the volatility asymmetry, we have tested standard GARCH models that take into account this stylized fact in Phase II.[12] Following Rodríguez and Ruiz (2009), we have estimated EGARCH models as the most flexible GARCH model that captures the asymmetric effect. In all three series of data, the asymmetric parameter is significant

[11] A survey of the empirical literature about this fact can be found in Taylor (2005).

[12] Borak et al. (2006), Paolella and Taschini (2008), Miclaus et al. (2008) and Benz and Trück (2009), among others, present GARCH models to analyze the conditional volatility of Phase I EUAs returns.

at the 1% significance level; however, the residuals of the estimated models still show persistence of heavy tails (see the last column in Table I). Therefore, when modeling EUA volatility, we suggest assuming fat-tailed unconditional distributions in order to capture all the volatility features of EUA return data.[13]

Finally, we have tested the relationship between the trading activity and volatility. Given that our measure of volatility is an intraday volatility, we have chosen two flow variables, the level of daily trading volume *(VOL)* and the change in the open interest *(ΔOI),* to calculate the cross correlations between these trading-related measures and volatility.

Panel A and B in Table VIII presents the results for the case of the volume and change in open interest, respectively. The contemporaneous cross correlation coefficients in the case of volume are positive and significant (76%, 88%, and 84% for 2008, 2009 and 2010 futures contract, respectively). The same occurs in the case of the open interest (17%, 32%, and 27% for 2008, 2009 and 2010 futures contracts, respectively). Furthermore, the cross correlations for lags from one to ten decay very slowly in both measures and in all three futures contracts. All in all, these facts indicate that both trading-related measures should be considered as explanatory variables in volatility models. Additionally, following the classical approach in the financial literature that considers the volume as a proxy for day trading and speculative activity, and the open interest as a proxy to measure the hedging activity, we could say that both speculators and hedgers destabilize the EUA market.

[13] See Rachev and Mittnik (2000, chapter 4) for a comparison of conditional and unconditional distributional models for the returns on Nikkei 225 stock market index.

4.4. Commodity features

The last group of relevant stylized facts is focused on specific features observed in commodities series. The first one we study is the non-trading effect in EUA volatility in order to test whether the information flow is more evenly distributed around the clock in weather-sensitive markets than in the equity market. Firstly, we have tested a possible daily seasonality in returns or variances. Both non-parametric Kruskal-Wallis and Brown-Forsythe tests cannot reject the equality of medians and variances.[14] Therefore, returns and variances are evenly distributed over the trading days. Secondly, two subsamples have been generated for each maturity. We have separated the weekend from the rest of the week, with the returns from Friday closing to Monday closing standing for weekend returns. Finally, we have split each subsample into two, separating between trading periods (open to close returns, OC) and non-trading periods (close to open returns, CO).

The results are presented in Table IX. All three futures contracts show similar results. We cannot reject the equality in variances between weekend and weekdays both for trading and non-trading periods, with the exception of non-trading periods for the future 2009. However, when comparing volatility between trading and non-trading periods conditioned on weekend or weekdays, we reject the null hypothesis at the 1% level of significance (except for weekend periods for future 2009), showing that the trading volatility (OC) is higher than non-trading volatility (CO). Taking into account that the number of trading hours (7:00 to 17:00, London local time) is lower than the number of non-trading hours, our results clearly indicate that information flow is

[14] The Kruskal-Wallis statistic is 3.849 (p-value = 0.427) for the future 2008, 4.210 (p-value = 0.378) for the future 2009 and 6.4956 (p-value = 0.1651) for the future 2010. The Brown-Forsythe statistic takes the values 1.591 (p-value = 0.174), 1.817 (p-value = 0.123) and 1.9257 (p-value = 0.1037) for 2008, 2009 and 2010 futures contracts, respectively.

concentrated during the business day, similar to the equity markets, and does not evolve randomly around the clock.

A second phenomenon characteristic of commodities futures is the negative correlation with stocks and bonds (see Gorton and Rouwenhorst, 2006). We have analyzed this aspect by calculating the existing correlation between the EUA futures and the main European benchmarks for bonds and stocks markets. Specifically, we have chosen the Schatz bond future, the Bolb bond future and the Bund bond future as representatives of short-term, medium-term and long-term bonds, and the Euro Stoxx 50 future contract and its underlying asset as a benchmark for the stock market. Table X presents the Spearman's rank correlation coefficient between the different described assets and the three EUA futures contracts.

The significance of the correlation with all the assets can be seen. Nonetheless, the correlation is negative with bonds assets and positive with stocks and Brent, mainly in the 2009 and 2010 futures contracts. A possible explanation of these results can be found in the fact that in business cycle expansions (contractions), when the stock market is normally in a bullish (bearish) moment, the companies produce more (less) and as a consequence they pollute more (less) and need a higher (lower) number of EUAs. The expansions (contractions) are normally accompanied with an increase (a decrease) in the interest rates and a decrease (an increase) in bond prices. Note that the whole significant correlation picture has appealing implications for portfolio diversification purposes.

Finally, we test the property of *inflation hedge*. If the correlation between EUAs and inflation was significant and positive, they would let us hedge against inflation. To study this fact, we have carried out a monthly analysis. Furthermore, inflation has been divided into three types: the observed, the expected and the unexpected. It is interesting to extract the unexpected component of inflation because this is the part we are interested in hedging against since the expected component is anticipated by the interest rate, and with fixed income assets we might hedge against it. The Harmonized Index of Consumer Prices (HICP) monthly series has been chosen for the observed inflation.[15] The expected inflation is the free risk interest rate, reason why we use the 1-month Euribor rate as a proxy, leaving the non-expected inflation as the difference between the observed and the expected inflation.

Table XI shows the correlation coefficients between our asset and the different definitions of inflation. Note that the Spearman's correlation coefficients between the futures and the unexpected inflation are significant in all the futures contracts; therefore, as commodity futures, EUA assets could help us to hedge against inflation.

5. Conclusions

The objective of our paper is to study the stylized facts of EUA returns. Given that the Phase I (2005-2007) is generally considered as a pilot and learning phase, we have chosen 2008, 2009 and 2010 futures contracts to test the accomplishment of several statistical features that usually appear in both financial and commodities assets.

We have found evidence of intermittency, *aggregational gaussianity*, short-term predictability, Taylor effect, volatility clustering, asymmetric volatility, and positive relation between volatility and volume and between the volatility and the change in the open interest. Our findings suggest that temporal dependencies should be modeled with

[15] Eurostat defines the Harmonized Index of Consumer Prices (HICPs) as an economic indicator constructed to measure the changes over time in the prices of consumer goods and services acquired by households. The HICPs give comparable measures of inflation in the euro-zone, the EU, the European Economic Area and for other countries including accession and candidate countries. They are calculated according to a harmonized approach and a single set of definitions. They provide the official measure of consumer price inflation in the euro-zone for the purposes of monetary policy in the euro area and assessing inflation convergence as required under the Maastricht criteria. The elected series is the European Union HICP with 25 countries. More details about this index can be found at http://ec.europa.eu/eurostat (last accessed on March 20, 2012).

ARMA-GARCH structures. However, the persistence of conditional heavy-tails indicates that in order to capture the volatility features of EUA return data; fat-tailed unconditional distributions should be assumed. Furthermore, unlike commodities properties, we have observed negative asymmetry, positive correlation with stocks indexes and higher volatility levels during the trading session, an indication that the EUA information flow is concentrated during the trading day and does not evolve randomly around the clock. The property of inflation hedge and the positive correlation with bonds, both characteristics being typical of commodity futures, are also detected. Therefore, our results indicate that EUAs do not behave like either common commodity futures or financial assets, and suggest that the EUA is a new asset class. The entirety of these facts, robust over time, has appealing implications for portfolio analysis, volatility modeling, hedging activities and cointegration analysis.

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Table I. Summary statistics for EUA futures returns

This table presents the descriptive statistics for 2008, 2009 and 2010 EUA futures contracts traded at the ICE ECX market. Panel A, B and C present the statistics for the 2008, 2009 and 2010 EUA futures contracts, respectively. "Monday to Monday" ("Wednesday to Wednesday") column shows the results for weekly returns calculated from Monday (Wednesday) close to Monday (Wednesday) close. "Monthly Based day 1" presents the results for monthly returns, calculated from the first trading day of each month to the last trading day in the same month. "Monthly Based day 15", "Monthly Based day 14" and "Monthly Based day 20" show the results for monthly returns, calculated from one day in mid-month to the same day in the next month, being the number for that specific day. "Residuals EGARCH" stands for the statistics of the residuals obtained after fitting an AR(1)-EGARCH(1,1) model for each contract. "K-S stat" stands for Kolmogorov-Smirnov statistic that tests the null hypothesis of the normality of the distribution. "2008 EUA Futures Contract" refers to the futures contract maturing on December 15th, 2008, "2009 EUA Futures Contract" refers to the futures contract maturing on December 14th, 2009 and "2010 EUA Futures Contract" refers to the futures contract maturing on December 20th, 2010.

Panel A: 2008 EUA Futures Contract

	Daily	Monday to Monday	Wednesday to Wednesday	Monthly Based day 1	Monthly Based day 15	Residuals EGARCH
Mean	-0.0001	-0.0007	-0.0007	-0.0011	-0.0025	-0.0140
Median	0.0013	0.0072	0.0033	-0.0026	0.0022	0.0209
Maximum	0.1865	0.2076	0.1441	0.3189	0.2786	3.9433
Minimum	-0.2882	-0.5146	-0.3757	-0.3780	-0.3405	-7.5034
Std. Dev.	0.0286	0.0767	0.0646	0.1532	0.1317	1.0003
Skewness	-1.3166	-1.8022	-1.3332	-0.2364	-0.2879	-0.5897
Kurtosis	17.9459	13.1149	9.5885	2.7371	3.0530	7.6354
Jarque-Bera	8,982.2510	912.8140	397.8340	0.5240	0.5990	891.3000
p-value	0.0000	0.0000	0.0000	0.7690	0.7410	0.0000
K-S stat	2.9130	1.2370	1.1710	0.5710	0.5210	2.6360
p-value	0.0000	0.0940	0.1280	0.9000	0.9490	0.0000
Observations	936	190	189	43	43	935

Panel B: 2009 EUA Futures Contract

	Daily	Monday to Monday	Wednesday to Wednesday	Monthly Based day 1	Monthly Based day 14	Residuals EGARCH
Mean	-0.0001	-0.0009	-0.0006	-0.0035	-0.0031	-0.0085
Median	0.0007	0.0050	0.0032	-0.0013	0.0132	0.0283
Maximum	0.1932	0.2069	0.1782	0.3219	0.4039	3.6552
Minimum	-0.2811	-0.5087	-0.3667	-0.3697	-0.4580	-7.8527
Std. Dev.	0.0286	0.0757	0.0649	0.1498	0.1487	1.0003
Skewness	-0.8873	-1.4620	-1.0739	-0.2569	-0.3153	-0.5654
Kurtosis	14.4420	10.9417	8.0011	2.7422	4.1379	7.1086
Jarque-Bera	6,647.5940	722.1760	2.9740	0.7570	3.8780	899.6650
p-value	0.0000	0.0000	0.0000	0.6850	0.1440	0.0000
K-S stat	2.9180	1.2680	1.3740	0.6240	0.6300	2.9260
p-value	0.0000	0.0800	0.0460	0.8310	0.8220	0.0000
Observations	1,190	242	241	55	55	1,189

Table I. Summary statistics for EUA futures returns (continued)

Panel C: 2010 EUA Futures Contract

	Daily	Monday to Monday	Wednesday to Wednesday	Monthly Based day 1	Monthly Based day 20	Residuals EGARCH
Mean	-0.0001	-0.0008	-0.0005	-0.0015	-0.0030	-0.0003
Median	0.0002	0.0019	0.0018	-0.0020	-0.0020	0.0005
Maximum	0.1912	0.2078	0.1830	0.3249	0.2801	0.1979
Minimum	-0.2743	-0.5016	-0.3582	-0.3654	-0.3710	-0.2711
Std. Dev.	0.0268	0.0708	0.0597	0.1392	0.1254	0.0267
Skewness	-0.8500	-1.4094	-1.0625	-0.2087	-0.2978	-0.8110
Kurtosis	14.5575	11.3714	8.6198	3.1254	3.5760	14.4896
Jarque-Bera	8,222.0183	959.0620	442.2060	0.5304	1.9451	8,106.6428
p-value	0.0000	0.0000	0.0000	0.7670	0.3781	0.0000
K-S stat	3.0339	1.5029	1.7856	0.4845	0.5570	3.0453
p-value	0.0000	0.0218	0.0034	0.9730	0.9157	0.0000
Observations	1,446	295	294	67	68	1,445

Table II. Outlier detection

This table presents the outlier detection based on daily returns for the EUA 2008, 2009 and 2010 futures contracts. "5% VaR" ("95% VaR") provides the outlier detection through the Value at Risk method, considering as extreme positive (negative) outliers those returns which are over (under) the 5% 1-day VaR (the 95% 1-day VaR). Total VaR considers the aggregation of extreme returns. "Huber" provides the outlier detection through the M-Huber estimator. The table is divided into three panels. Panel A summarizes the outlier detection. Panel B presents the magnitude of the outliers detected in terms of standard deviations of returns (σ). Panel C shows the number of clusters of outliers that have been detected. "2008 EUA Futures Contract" refers to the futures contract maturing on December 15th, 2008, "2009 EUA Futures Contract" refers to the futures contract maturing on December 14th, 2009 and "2010 EUA Futures Contract" refers to the futures contract maturing on December 20th, 2010.

Panel A: Outliers summary

	2008 EUA Futures Contract				2009 EUA Futures Contract				2010 EUA Futures Contract			
	5% VaR	95% VaR	Total VaR	Huber	5% VaR	95% VaR	Total VaR	Huber	5% VaR	95% VaR	Total VaR	Huber
Number of observations	936				1,190				1,446			
Number of outliers	47	46	93	156	60	59	119	199	73	72	145	231
% Number of outliers	5.02%	4.91%	9.94%	16.67%	5.04%	4.96%	10.00%	16.72%	5.05%	4.98%	10.03%	15.98%
VaR return	3.89%	-4.53%	-	-	3.98%	-4.56%	-	-	3.78%	-4.24%	-	-
Number of positive outliers	47	0	47	66	60	0	60	89	73	0	73	105
Number of negative outliers	0	46	46	90	0	59	59	110	0	72	72	126

Panel B: Size of Outliers (σs)

	2008 EUA Futures Contract				2009 EUA Futures Contract				2010 EUA Futures Contract			
	5% VaR	95% VaR	Total VaR	Huber	5% VaR	95% VaR	Total VaR	Huber	5% VaR	95% VaR	Total VaR	Huber
From 0 to 1	0	0	0	0	0	0	0	0	0	0	0	0
From 1 to 2	34	20	54	118	42	28	70	150	48	35	83	170
From 2 to 3	8	18	26	24	11	22	33	33	17	25	42	41
From 3 to 4	4	4	8	9	6	5	11	11	5	8	13	13
From 4 to 5	0	1	1	1	0	1	1	1	2	0	2	2
From 5 to 6	0	2	2	2	0	2	2	2	0	3	3	3
From 6 to 7	1	0	1	1	1	0	1	1	0	0	0	0
From 7 to 8	0	0	0	0	0	0	0	0	1	0	1	1
From 8 to 9	0	0	0	0	0	0	0	0	0	0	0	0
From 9 to 10	0	0	0	0	0	1	1	1	0	0	0	0
From 10 to 11	0	1	1	1	0	0	0	0	0	1	1	1

Panel C: Clusters of Outliers

	2008 EUA Futures Contract				2009 EUA Futures Contract				2010 EUA Futures Contract			
	5% VaR	95% VaR	Total VaR	Huber	5% VaR	95% VaR	Total VaR	Huber	5% VaR	95% VaR	Total VaR	Huber
1 value	37	36	63	84	44	45	73	106	57	54	94	129
2 values	5	5	12	24	8	7	17	31	8	9	18	30
3 values	0	0	2	5	0	0	4	4	0	0	5	6
4 values	0	0	0	1	0	0	0	2	0	0	0	2
5 values	0	0	0	1	0	0	0	1	0	0	0	2
6 values	0	0	0	0	0	0	0	1	0	0	0	1

Table III. Unit root tests

This table summarizes the Kwiatkowski et al.'s (1992) unit root tests for the time series of EUAs future prices both in levels and in first differences. We test the null of stationarity with intercept and deterministic time trend for the price series in levels. The critical value (at the 1% level) is 0.216 (see Table 1 in Kwiatkowski et al.'s paper, p. 166). If rejected, we then test the null of stationarity plus intercept for the time series in first differences. The critical value is 0.739 (see Table 1 in Kwiatkowski et al.'s paper, p. 166). "2008 EUA Futures Contract" refers to the futures contract maturing on December 15th, 2008, "2009 EUA Futures Contract" refers to the futures contract maturing on December 14th, 2009 and "2010 EUA Futures Contract" refers to the futures contract maturing on December 20th, 2010.

Futures Contract	Level	Differences
2008 EUA Futures Contract	0.3281	0.0949*
2009 EUA Futures Contract	0.3867	0.0783*
2010 EUA Futures Contract	0.3392	0.0733*

* The null of stationarity cannot be rejected (at the 1% level)

Table IV. Autocorrelation tests

This table provides the first 10 lagged sample autocorrelation coefficients for the 2008, 2009 and 2010 EUA futures contracts returns. ρ stands for the Spearman's rank correlation coefficient. "2008 EUA Futures Contract" refers to the futures contract maturing on December 15th, 2008, "2009 EUA Futures Contract" refers to the futures contract maturing on December 14th, 2009 and "2010 EUA Futures Contract" refers to the futures contract maturing on December 20th, 2010.

	2008 EUA Futures Contract		2009 EUA Futures Contract		2010 EUA Futures Contract	
Lag	ρ	p-value	ρ	p-value	ρ	p-value
1	0.1240	0.0001	0.1090	0.0002	0.0779	0.0031
2	-0.0095	0.7714	-0.0160	0.5814	-0.0250	0.3421
3	0.0444	0.1748	0.0480	0.0979	0.0395	0.1339
4	0.0386	0.2381	0.0484	0.0949	0.0385	0.1434
5	0.0083	0.7996	0.0066	0.8198	0.0131	0.6183
6	-0.0003	0.9936	0.0044	0.8798	0.0016	0.9526
7	-0.0280	0.3922	-0.0170	0.5577	-0.0143	0.5875
8	0.0221	0.4987	0.0156	0.5911	0.0144	0.5858
9	-0.0083	0.7998	0.0073	0.8023	0.0259	0.3257
10	0.0660	0.0435	0.0548	0.0587	0.0398	0.1315

Table V. Run tests

This table reports the run test statistics for all three EUA futures contracts where the null hypothesis is that returns are generated in a random way. The table shows the observed and the expected number of runs, the statistic and its p-value. "2008 EUA Futures Contract" refers to the futures contract maturing on December 15th, 2008, "2009 EUA Futures Contract" refers to the futures contract maturing on December 14th, 2009 and "2010 EUA Futures Contract" refers to the futures contract maturing on December 20th, 2010.

	Observed number of runs	Expected number of runs	Statistic	p-value
2008 EUA Futures Contract	429	469	2.4855	0.0129
2009 EUA Futures Contract	555	596	1.6820	0.0926
2010 EUA Futures Contract	698	724	1.3679	0.1797

Table VI. Taylor effect

This table provides the first 10 lagged sample autocorrelation coefficients for the 2008, 2009 and 2010 EUA futures contracts absolute returns. ρ stands for the Spearman's rank correlation coefficient. "2008 EUA Futures Contract" refers to the futures contract maturing on December 15th, 2008, "2009 EUA Futures Contract" refers to the futures contract maturing on December 14th, 2009 and "2010 EUA Futures Contract" refers to the futures contract maturing on December 20th, 2010.

	2008 EUA Futures Contract		2009 EUA Futures Contract		2010 EUA Futures Contract	
Lag	ρ	p-value	ρ	p-value	ρ	p-value
1	0.1071	0.0010	0.1322	0.0000	0.1301	0.0000
2	0.0498	0.1280	0.0848	0.0034	0.1106	0.0000
3	0.1202	0.0002	0.1533	0.0000	0.1583	0.0000
4	0.0792	0.0154	0.1012	0.0005	0.0964	0.0002
5	0.0873	0.0075	0.1156	0.0001	0.1233	0.0000
6	0.0907	0.0055	0.1331	0.0000	0.1398	0.0000
7	0.0639	0.0507	0.0722	0.0127	0.0776	0.0032
8	0.0740	0.0235	0.1153	0.0001	0.1268	0.0000
9	0.0861	0.0084	0.1102	0.0001	0.0988	0.0002
10	0.0466	0.1541	0.0758	0.0089	0.0874	0.0009

Table VII. Volatility-related features

Panel A presents the Spearman's autocorrelations coefficients (ρ) between the daily *Garman-Klass volatility* (σ) and the daily *Garman-Klass volatility* lagged τ periods. Panel B presents the Spearman's cross correlations coefficients between the daily *Garman-Klass volatility* and the daily futures return (r) lagged τ periods. "2008 EUA Futures Contract" refers to the futures contract maturing on December 15th, 2008, "2009 EUA Futures Contract" refers to the futures contract maturing on December 14th, 2009 and "2010 EUA Futures Contract" refers to the futures contract maturing on December 20th, 2010.

Panel A

$\rho_S(\sigma,\sigma_{-\tau})$	2008 EUA Futures Contract		2009 EUA Futures Contract		2010 EUA Futures Contract	
Lag	Correlation	p-value	Correlation	p-value	Correlation	p-value
1	0.7634	0.0000	0.8428	0.0000	0.8641	0.0000
2	0.7132	0.0000	0.8384	0.0000	0.8514	0.0000
3	0.6968	0.0000	0.8267	0.0000	0.8400	0.0000
4	0.7207	0.0000	0.8304	0.0000	0.8287	0.0000
5	0.7189	0.0000	0.8266	0.0000	0.8377	0.0000
6	0.7036	0.0000	0.8090	0.0000	0.8249	0.0000
7	0.6796	0.0000	0.8128	0.0000	0.8243	0.0000
8	0.6515	0.0000	0.8034	0.0000	0.8218	0.0000
9	0.6651	0.0000	0.8025	0.0000	0.8181	0.0000
10	0.6592	0.0000	0.8156	0.0000	0.8226	0.0000

Panel B

$\rho_S(\sigma,r_{-\tau})$	2008 EUA Futures Contract		2009 EUA Futures Contract		2010 EUA Futures Contract	
Lag	Correlation	p-value	Correlation	p-value	Correlation	p-value
0	-0.1008	0.0020	-0.0931	0.0013	-0.0666	0.0113
1	-0.0915	0.0051	-0.0781	0.0070	-0.0564	0.0321
2	-0.0777	0.0174	-0.0608	0.0361	-0.0485	0.0652
3	-0.0626	0.0557	-0.0777	0.0074	-0.0637	0.0154
4	-0.0655	0.0453	-0.0614	0.0341	-0.0572	0.0298
5	-0.0613	0.0609	-0.0387	0.1821	-0.0580	0.0278
6	-0.0692	0.0342	-0.0630	0.0298	-0.0571	0.0304
7	-0.0506	0.1222	-0.0510	0.0787	-0.0341	0.1956
8	-0.0554	0.0901	-0.0497	0.0867	-0.0541	0.0402
9	-0.0572	0.0803	-0.0312	0.2815	-0.0497	0.0594
10	-0.0789	0.0158	-0.0676	0.0197	-0.0589	0.0256

Table VIII. Trading-related features

Panel A presents the Spearman's cross correlations coefficients (ρ) between the daily *Garman-Klass volatility* (σ) and the daily trading volume (*VOL*) lagged τ periods. Panel B presents the Spearman's cross correlations coefficients between the daily *Garman-Klass volatility* (σ) and the change in the daily open interest (*ΔOI*) lagged τ periods. "2008 EUA Futures Contract" refers to the futures contract maturing on December 15th, 2008, "2009 EUA Futures Contract" refers to the futures contract maturing on December 14th, 2009 and "2010 EUA Futures Contract" refers to the futures contract maturing on December 20th, 2010.

Panel A

$\rho_S(\sigma, VOL_{-\tau})$	2008 EUA Futures Contract		2009 EUA Futures Contract		2010 EUA Futures Contract	
Lag	Correlation	p-value	Correlation	p-value	Correlation	p-value
0	0.7644	0.0000	0.8832	0.0000	0.8403	0.0000
1	0.7070	0.0000	0.8559	0.0000	0.8210	0.0000
2	0.6875	0.0000	0.8492	0.0000	0.8122	0.0000
3	0.6865	0.0000	0.8512	0.0000	0.8132	0.0000
4	0.6980	0.0000	0.8454	0.0000	0.8082	0.0000
5	0.6956	0.0000	0.8444	0.0000	0.8082	0.0000
6	0.6831	0.0000	0.8377	0.0000	0.8049	0.0000
7	0.6758	0.0000	0.8354	0.0000	0.8045	0.0000
8	0.6667	0.0000	0.8298	0.0000	0.7981	0.0000
9	0.6710	0.0000	0.8352	0.0000	0.7918	0.0000
10	0.6690	0.0000	0.8390	0.0000	0.7946	0.0000

Panel B

$\rho_S(\sigma, \Delta OI_{-\tau})$	2008 EUA Futures Contract		2009 EUA Futures Contract		2010 EUA Futures Contract	
Lag	Correlation	p-value	Correlation	p-value	Correlation	p-value
0	0.1720	0.0000	0.3186	0.0000	0.2705	0.0000
1	0.1146	0.0006	0.2767	0.0000	0.2658	0.0000
2	0.1025	0.0021	0.2817	0.0000	0.2460	0.0000
3	0.1319	0.0001	0.2934	0.0000	0.2536	0.0000
4	0.1286	0.0001	0.2977	0.0000	0.2554	0.0000
5	0.1087	0.0011	0.2793	0.0000	0.2570	0.0000
6	0.1019	0.0022	0.2581	0.0000	0.2641	0.0000
7	0.1148	0.0006	0.2581	0.0000	0.2504	0.0000
8	0.0841	0.0117	0.2588	0.0000	0.2419	0.0000
9	0.1203	0.0003	0.2838	0.0000	0.2325	0.0000
10	0.1394	0.0000	0.2649	0.0000	0.2334	0.0000

Table IX. Information flows

This table reports the Brown-Forsythe statistic (BF-Statistic) that tests the null of equality of variances among trading and non-trading periods. Panels A, B and C present the results for weekends and for weekdays for 2008, 2009 and 2010 futures contracts, respectively. Weekend results are based on returns from Friday close to Monday close and weekday results are based on returns from Monday close to Friday close. The table also reports the number of observations and the annualized volatility in percentage for trading (σ_{OC}) and non-trading (σ_{CO}) periods. "2008 EUA Futures Contract" refers to the futures contract maturing on December 15th, 2008, "2009 EUA Futures Contract" refers to the futures contract maturing on December 14th, 2009 and "2010 EUA Futures Contract" refers to the futures contract maturing on December 20th, 2010.

Panel A: 2008 EUA Futures Contract	Number of observations	σ_{OC}	σ_{CO}	BF-Statistic	p-value
Weekend	144	47.43	25.17	11.3814	0.0008
Weekdays	574	41.01	28.24	30.0853	0.0000
BF-Statistic		0.0144	0.7702		
p-value		0.9044	0.3805		
Total	718	42.36	27.66	41.2757	0.0000

Panel B: 2009 EUA Futures Contract	Number of observations	σ_{OC}	σ_{CO}	Statistic	p-value
Weekend	142	42.14	34.53	2.0256	0.1558
Weekdays	572	39.88	28.14	25.2061	0.0000
Statistic		0.6069	6.3929		
p-value		0.4362	0.0117		
Total	714	40.32	29.57	25.5893	0.0000

Panel C: 2010 EUA Futures Contract	Number of observations	σ_{OC}	σ_{CO}	Statistic	p-value
Weekend	161	34.21	25.17	10.7123	0.0012
Weekdays	656	30.76	24.91	32.4802	0.0000
Statistic		1.1193	0.0713		
p-value		0.2904	0.7895		
Total	817	31.49	24.95	43.1415	0.0000

Table X. Correlation with bonds, stocks and Brent

The table gives the Spearman's rank correlation coefficients and their p-value between the EUA 2008, 2009 and 2010 futures contracts and the Schatz bond future (short-term fixed rent), the Bolb bond future (medium-term fixed rent), the Bund bond future (long-term fixed rent), the Euro Stoxx 50 future, the Euro Stoxx 50 index, and the Brent futures contract. "2008 EUA Futures Contract" refers to the futures contract maturing on December 15th, 2008, "2009 EUA Futures Contract" refers to the futures contract maturing on December 14th, 2009 and "2010 EUA Futures Contract" refers to the futures contract maturing on December 20th, 2010.

	2008 EUA Futures Contract		2009 EUA Futures Contract		2010 EUA Futures Contract	
Asset	ρ	p-value	ρ	p-value	ρ	p-value
Schatz bond futures	-0.0950	0.0038	-0.1311	0.0000	-0.1145	0.0000
Bolb bond futures	-0.0971	0.0031	-0.1442	0.0000	-0.1248	0.0000
Bund bond futures	-0.0951	0.0038	-0.1465	0.0000	-0.1268	0.0000
Euro Stoxx 50 futures	0.0585	0.0751	0.1476	0.0000	0.1412	0.0000
Euro Stoxx 50 Index	0.0577	0.0787	0.1434	0.0000	0.1362	0.0000
Brent oil futures	0.2413	0.0000	0.2499	0.0000	0.2302	0.0000

Table XI. Inflation hedge

The table shows the Spearman's rank correlation coefficients and its p-value between the EUA futures contracts returns and the series of the observed, expected and non-expected inflation. The number of monthly observations is 43, 55 and 67 for the 2008, 2009 and 2010 EUA futures contracts, respectively. "2008 EUA Futures Contract" refers to the futures contract maturing on December 15th, 2008, "2009 EUA Futures Contract" refers to the futures contract maturing on December 14th, 2009 and "2010 EUA Futures Contract" refers to the futures contract maturing on December 20th, 2010.

	Correlation		
2008 EUA Futures Contract	Observed inflation	Expected inflation	Non-expected inflation
Correlation coefficient	0.2895	-0.0908	0.3241
Sig. (bilateral)	0.0601	0.5627	0.0345

	Correlation		
2009 EUA Futures Contract	Observed inflation	Expected inflation	Non-expected inflation
Correlation coefficient	0.2953	-0.0618	0.2863
Sig. (bilateral)	0.0290	0.6542	0.0345

	Correlation		
2010 EUA Futures Contract	Observed inflation	Expected inflation	Non-expected inflation
Correlation coefficient	0.3379	-0.0316	0.2973
Sig. (bilateral)	0.0054	0.7998	0.0149

Figure 1. Prices evolution

Figure 1 shows the prices evolution for the 2008, 2009 and 2010 EUA futures contracts. The period sample goes from April 22nd, 2005 to December 15th, 2008 for the first contract, from April 22nd, 2005 to December 14th, 2009 for the second one and from April 22nd, 2005 to December 20th, 2010 for the last one.

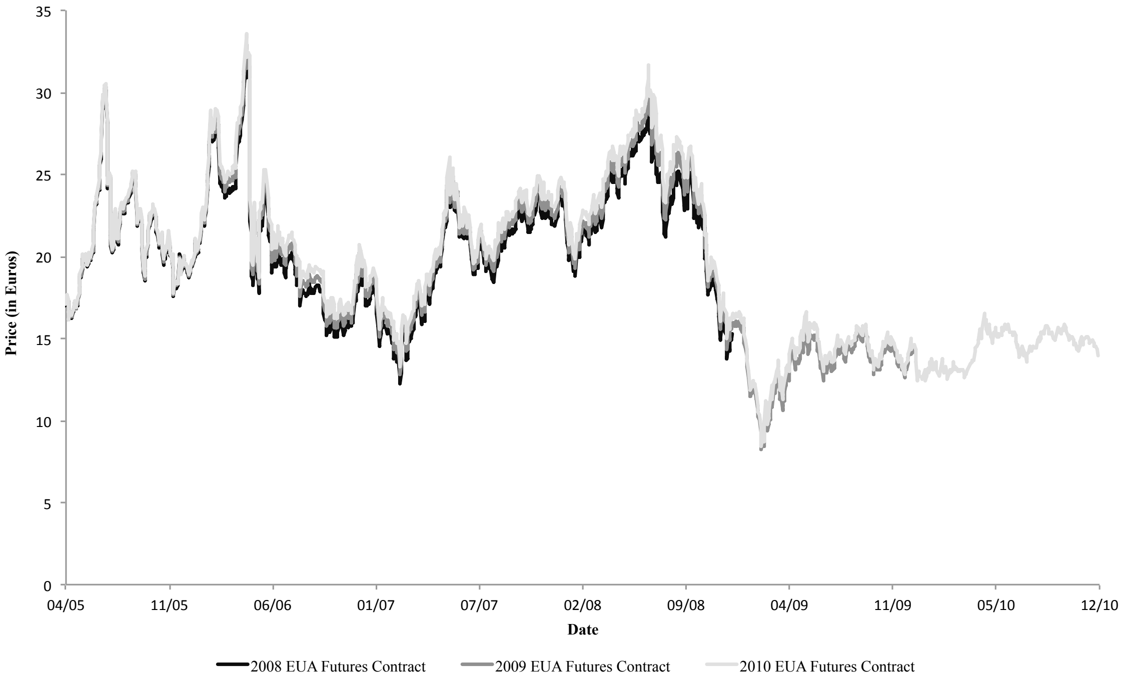

Figure 2. Returns histograms

Figures 2a, 2b and 2c depict the histograms of the daily returns for the 2008, 2009 and 2010 EUA futures contracts, respectively, in comparison with the histogram of a normal distribution. The period sample goes from April 22nd, 2005 to December 15th, 2008 for the first contract, from April 22nd, 2005 to December 14th, 2009 for the second one and from April 22nd, 2005 to December 20th, 2010 for the last one, collecting 936, 1,190 and 1,446 daily returns for 2008, 2009 and 2010 EUA ECX futures contracts, respectively.

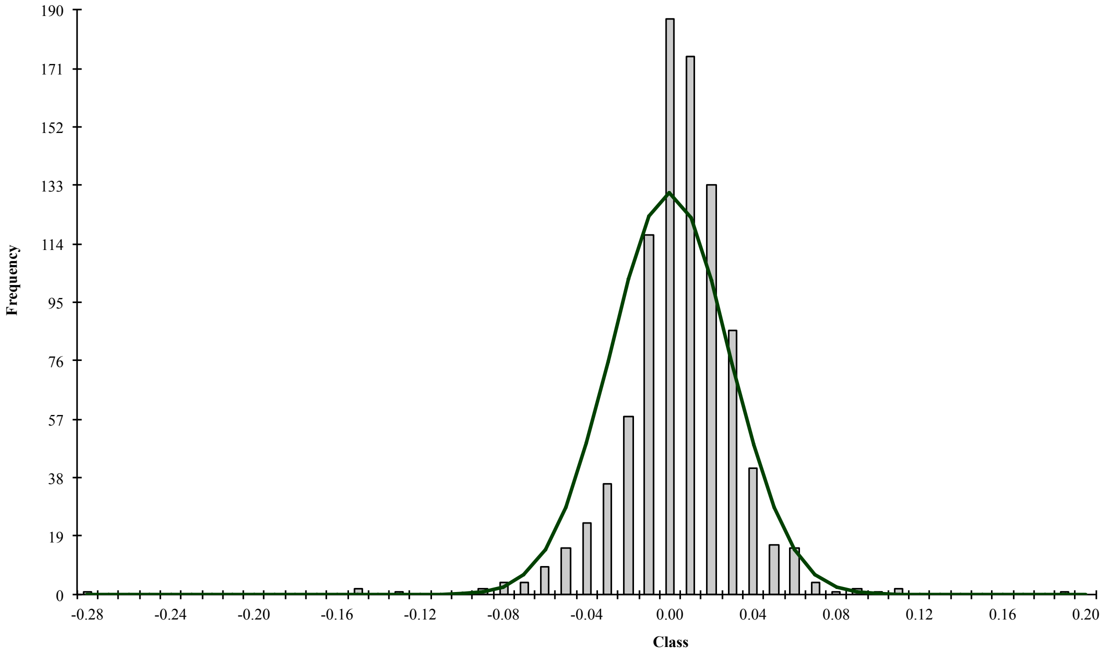

Figure 2a. 2008 EUA Futures Contract

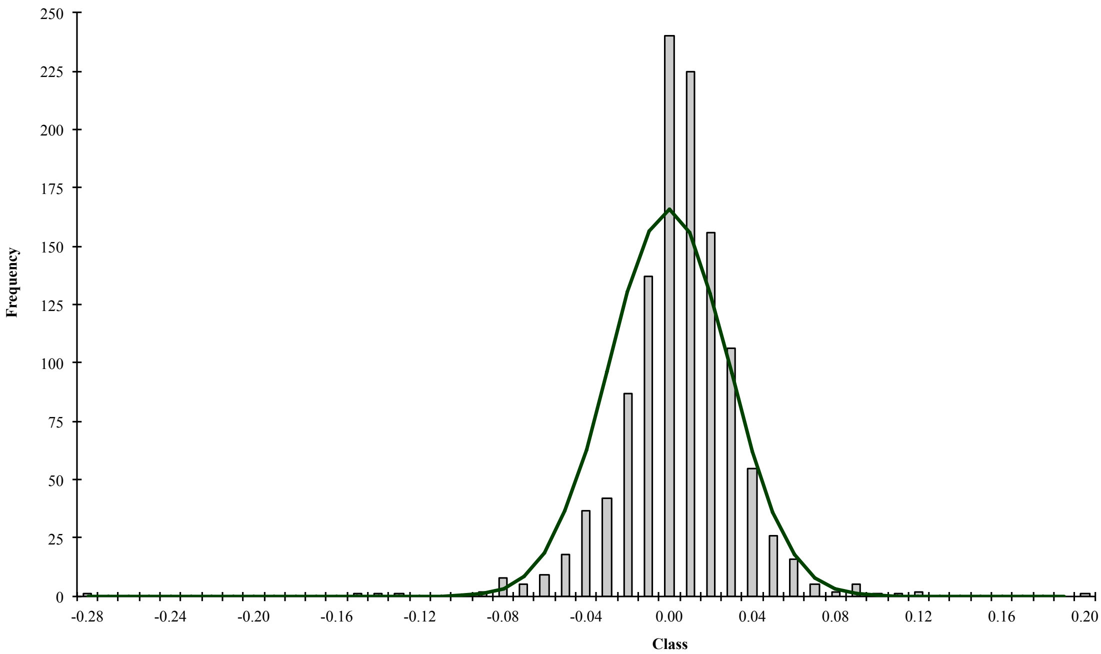

Figure 2b. 2009 EUA Futures Contract

Figure 2. Returns histograms (continued)

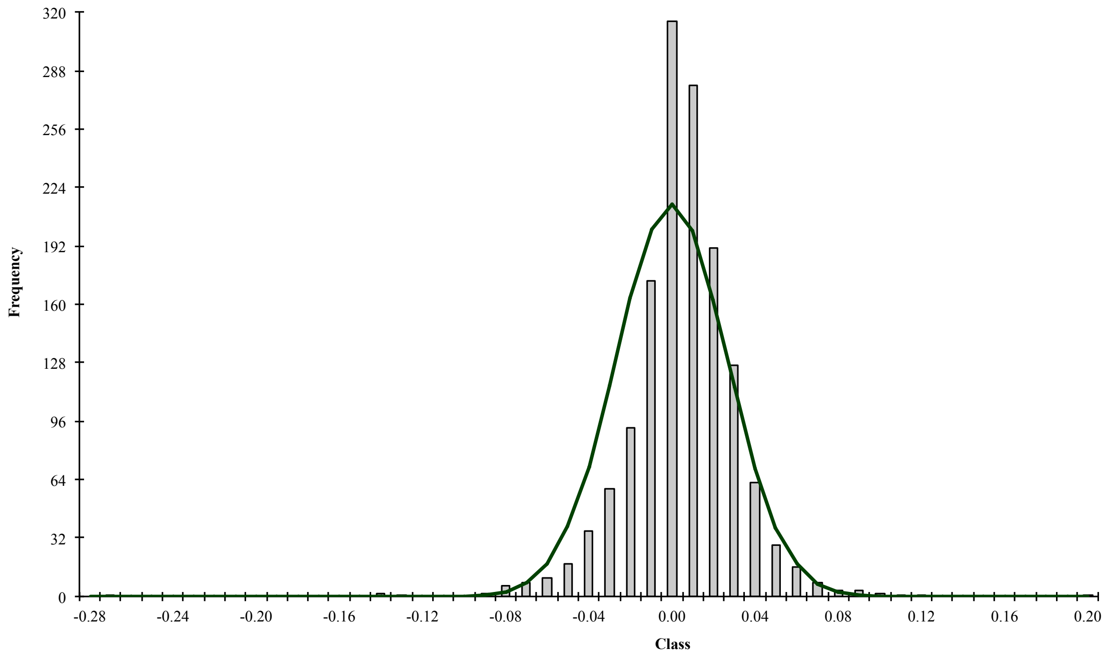

Figure 2c. 2010 EUA Futures Contract

Figure 3. Volatility clustering

Figures 3a, 3c and 3e exhibit the squared returns representation for the 2008, 2009 and 2010 EUA futures contracts, respectively. Figure 3b, 3d and 3f show the Garman-Klass volatility representation for the 2008, 2009 and 2010 EUA futures contracts, respectively. Volatility clustering is observed in all figures. "2008 EUA Futures Contract" refers to the futures contract maturing on December 15th, 2008, "2009 EUA Futures Contract" refers to the futures contract maturing on December 14th, 2009 and "2010 EUA Futures Contract" refers to the futures contract maturing on December 20th, 2010.

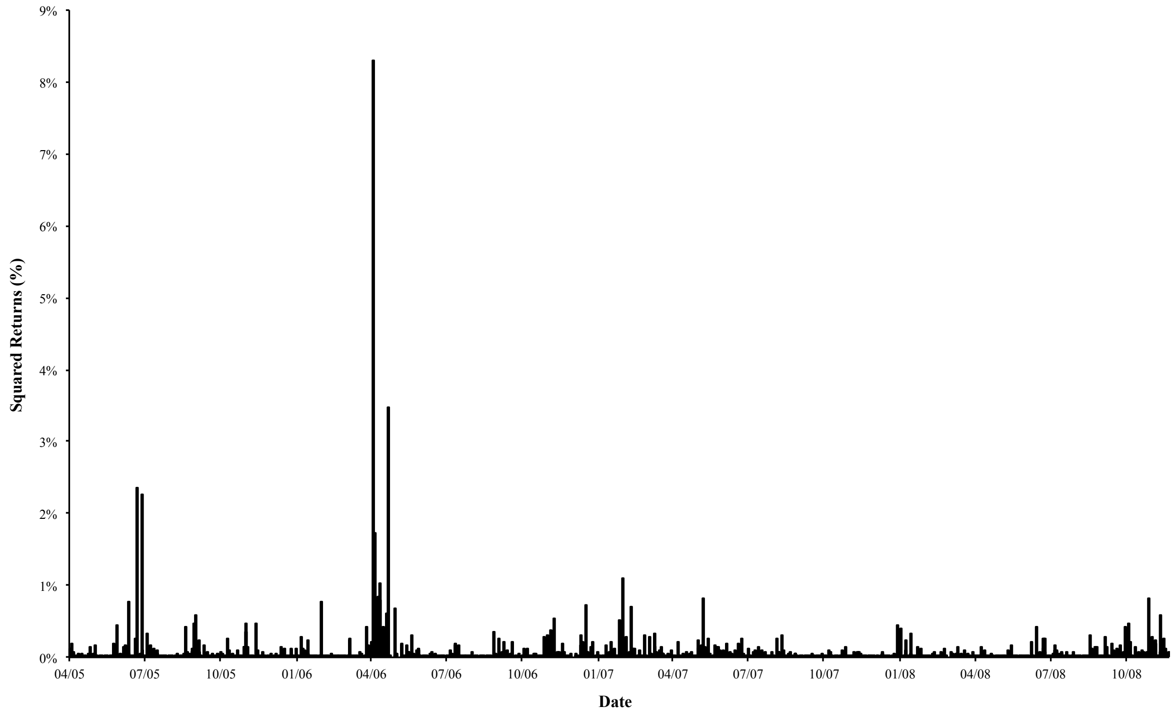

Figure 3a. Squared returns representation for 2008 EUA Futures Contract

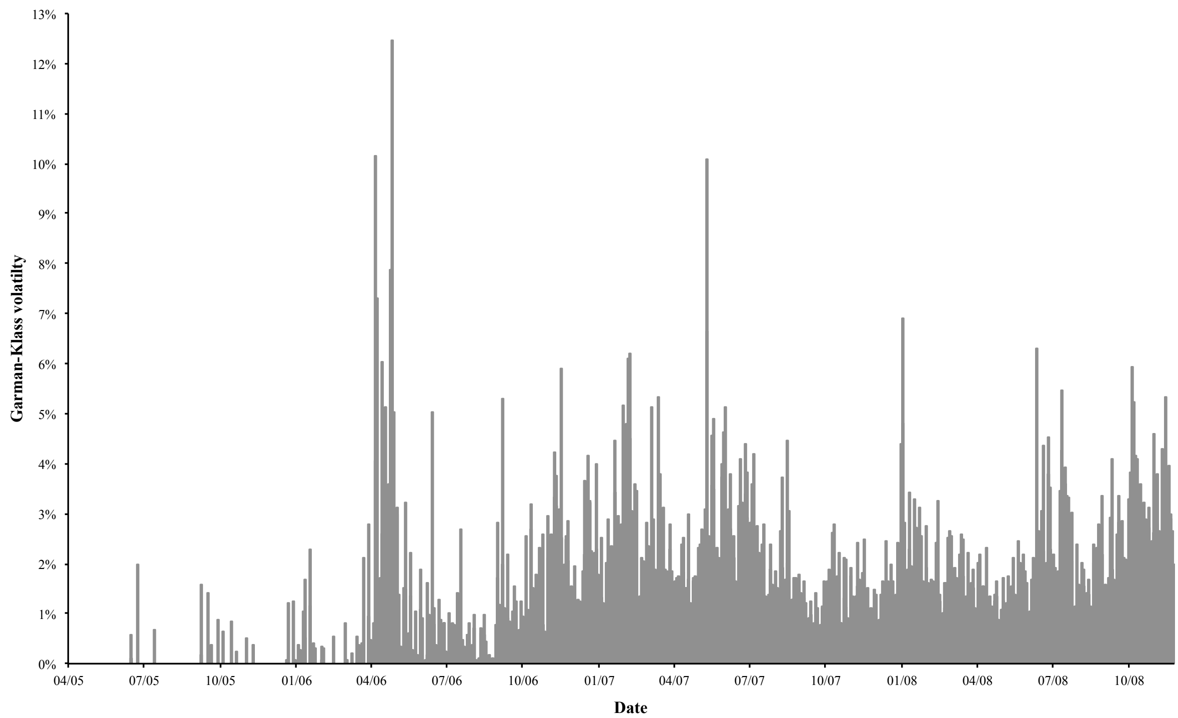

Figure 3b. Garman-Klass volatility for 2008 EUA Futures Contract

Figure 3. Volatility clustering (continued)

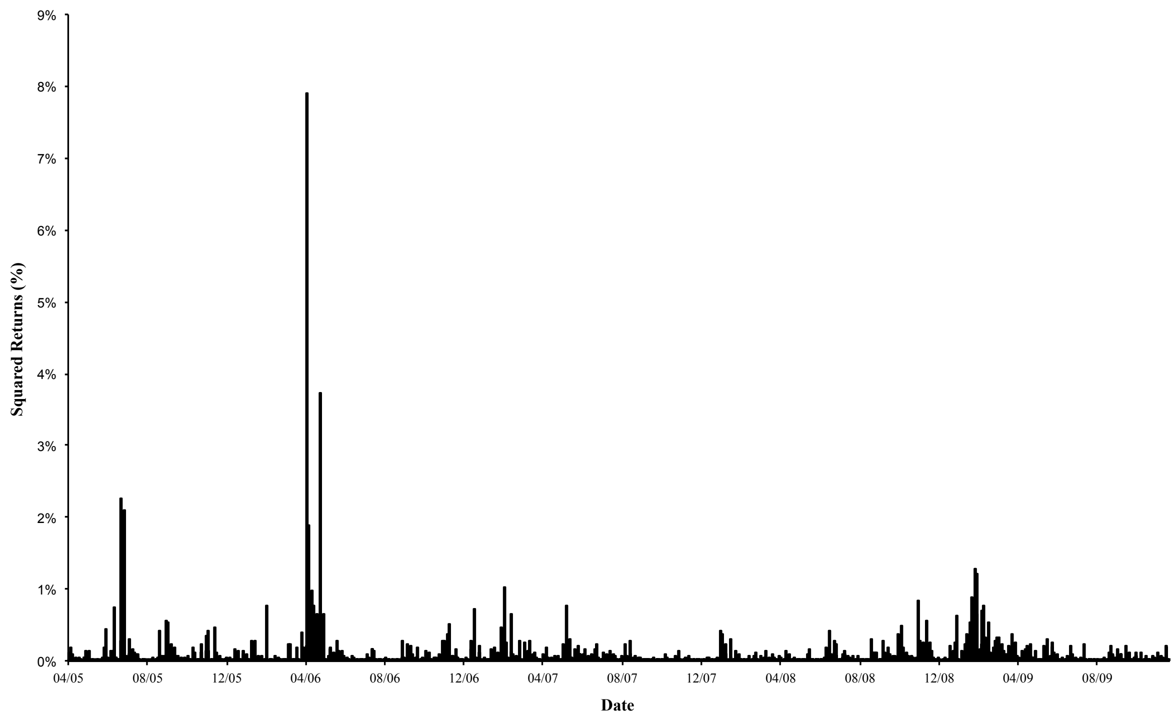

Figure 3c. Squared returns representation for 2009 EUA Futures Contract

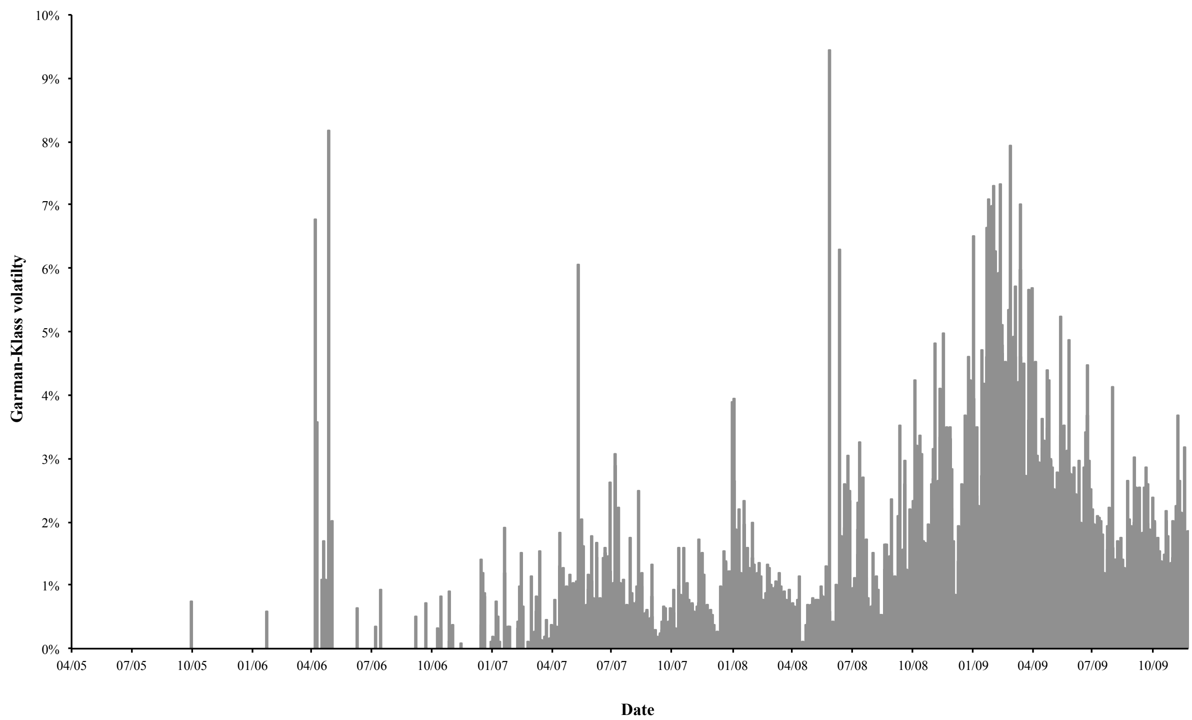

Figure 3d. Garman-Klass volatility for 2009 EUA Futures Contract

Figure 3. Volatility clustering (continued)

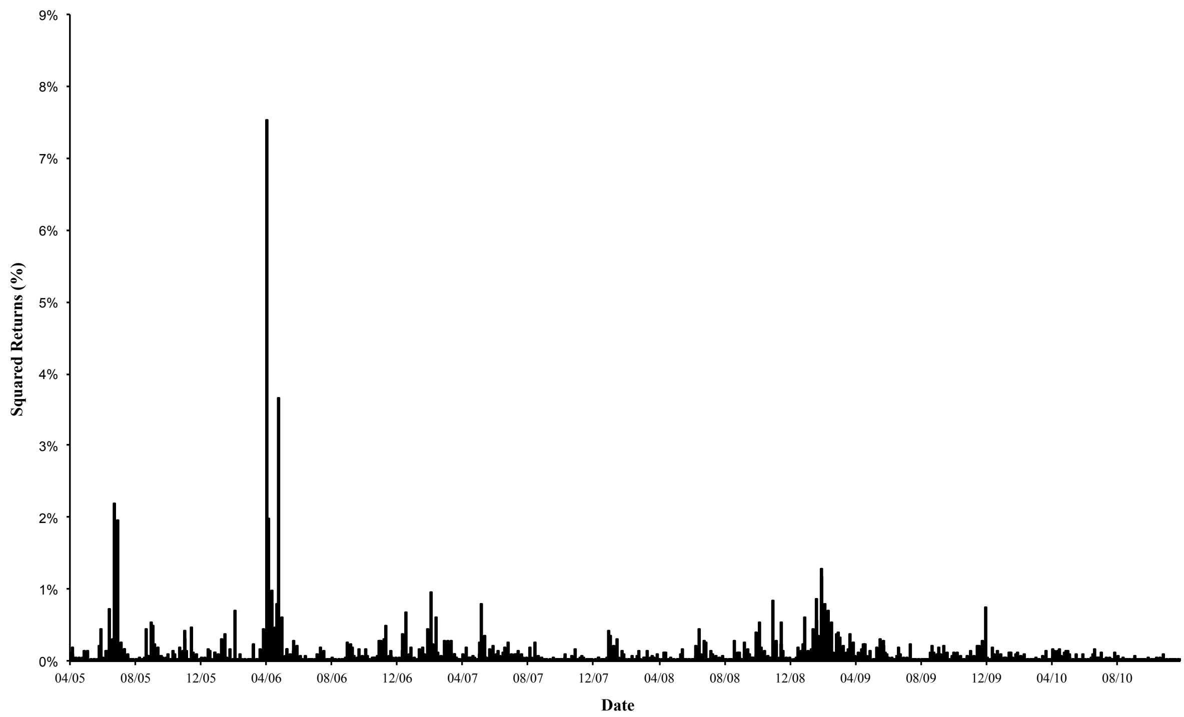

Figure 3e. Squared returns representation for 2010 EUA Futures Contract

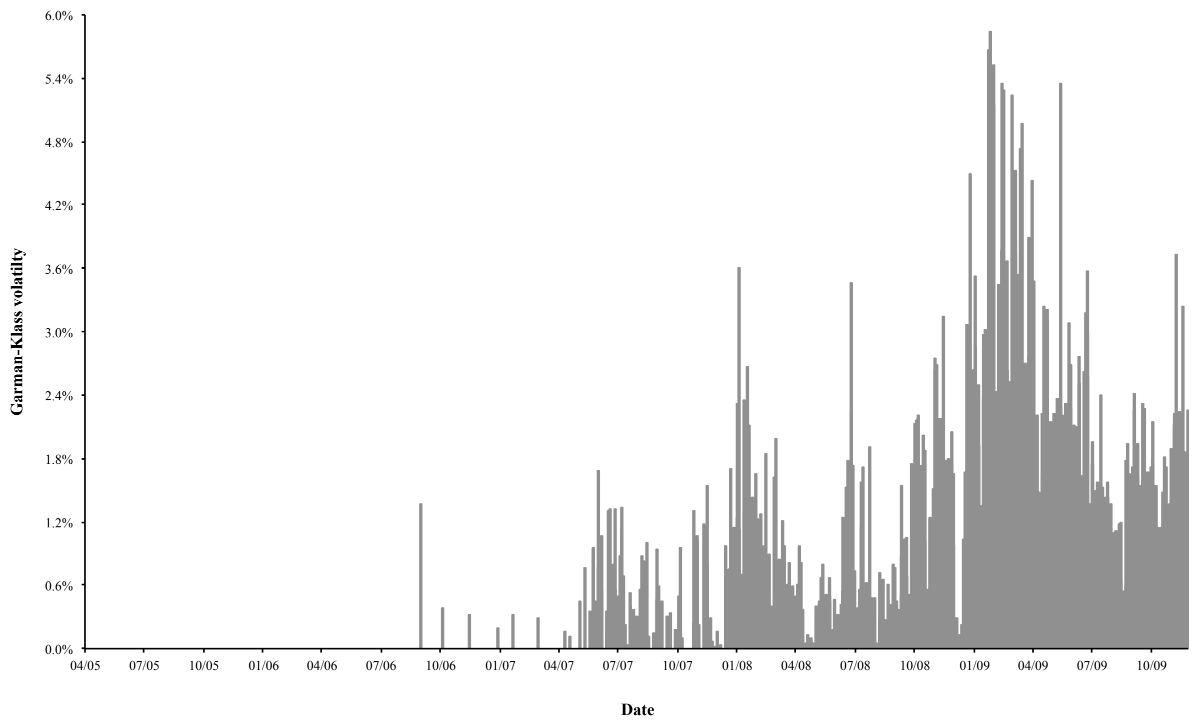

Figure 3f. Garman-Klass volatility for 2010 EUA Futures Contract

Chapter II

Rolling Over EUAs and CERs

1. Introduction

The first decision to take before carrying out an empirical analysis with EUAs and CERs prices both for hedging and for academic purposes is to decide which data they are going to take. Hedgers that face carbon risk price for a series of years/periods can use a "strip" of derivative contracts to avoid such risk, each with a different delivery date, or alternatively, use a stack hedge, in which the most nearby and/or liquid contract is used, and it is rolled over to the next-to-nearest contract as time passes.

In the first case, we find papers by Uhrig-Homburg and Wagner (2009), Chevallier and Benoit (2010), Rittler (2012) and Palao and Pardo (2012), that employ the entire lifespan of each EUA futures contract for the econometric estimation, and therefore, carry out their analysis using directly the available series. In the second case, researchers have to decide how to construct a continuous futures series using the different maturity contracts available. Some papers linked the different maturities using the expiration day as the timing for the rollover. This is the case for papers such as Mansanet-Bataller et al. (2011), who study EUA and CER price drivers; Chevallier (2010), who analyzes the inter-relationships between EUAs and CERs price series; Chevallier (2011), who proposes a model of carbon price interactions with macroeconomic and energy dynamics; and Mansanet-Bataller and Pardo (2011), who consider EUAs as an additional investing option in the framework of portfolio management. Another criterion is followed by Koenig (2011). He studies correlation in carbon and energy markets using daily observations from April 2005 to August 2010. To construct a reference price for EUAs, he combines three maturities into one single EUA future price series, labeled "EUA Tracker". During Phase I, "EUA Tracker" is equal to the price of the December 2007 contract. In Phase II, "EUA Tracker" switches to the December 2009 contract, until its date of maturity, after which it switches to the

December 2010 contract. Finally, the study of the evolution of liquidity in carbon futures markets by Medina et al. (2011) analyses the timeline of the liquidity in the European carbon market and uses the maximum volume criterion in order to obtain the most tradable contract series. After this selected review of several CO_2 studies which offer a variety of criteria to link series, the question is, can the election of the rollover date affect the empirical results obtained in these papers? The analysis that follows tries to provide an answer to this question.

The literature on rolling over futures contracts used to link the data of the nearest future contract up to its maturity with the following contract on the next day. This was the most popular method until Samuelson (1965) detected an abnormal volatility in the last weeks of life of futures contracts, which did not appear in the spot series. Thus, if continuous series were constructed taking as reference the prices of the nearest futures contract up to its maturity, the (abnormal) volatility could distort the conclusions reached from the statistical inferences. Due to this finding, some papers proposed different methodologies to try to avoid the possible abnormal volatility. Junkus (1986) constructs series without taking into account the data from the first day of the month of delivery until the day of maturity when studying weekend and day of the week effects in returns on stock index futures. Ma et al. (1992), in addition to this criterion and the delivery day method, use also the first notice day to link the different contracts and compare the different series obtained. The first notice day is defined as the date on which the broker warns their customers that the date of delivery is near, which is done two weeks prior to delivery. Finally, Geiss (1995) suggests an alternative method that constructs continuous futures series producing a price index which is a weighted average of observed prices for contracts with different expiration dates.

Ma et al. (1992) analyzed the rollover date in several futures contracts with different underlying assets and concluded that the differences between the return series obtained with different criteria were significant, and the best methodology depended on the underlying asset. Carchano and Pardo (2009) analyzed the relevance of the choice of the rolling over date using several methodologies for the case of stock index futures and they concluded that regardless of the criterion applied, there are not significant differences between the series obtained. Finally, Saunier (2010) studied the effect of using different rollover methodologies from the point of view of the investor's commodities portfolio yield, and determined that a trader's profit depends on the rollover choice. On the whole, the miscellany of results obtained in these studies implies that a specific empirical analysis must be carried out for each individual futures contract.

Unlike previous studies, in this paper we carry out not only an analysis in terms of returns distribution, but also a liquidity analysis. Although different rollover criteria can provide similar long return series, following specific criteria to do the rollover might not offer appropriate market liquidity conditions. For this reason, using the number of transactions, we create long future transaction series based on the different rollover criteria and we compare their levels of trading activity. Doing that, we can test if the methodology considered proper for constructing long futures return series offers also the most suitable liquidity context.

The behavior of the prices of European Union Allowances (EUAs) and Certified Emission Reductions (CERs) are of interest for polluting companies, investors and academics. Although EUAs and CERs spot markets exist, Uhrig-Homburg and Wagner (2009) and Rittler (2012) identify the price traded in the futures markets as the main reference in the price discovery process when analyzing the relationships between spot and future markets within the first and second commitment period of the European Union emission trading scheme, respectively.

This paper analyzes the relevance of the choice of the rollover date for European Union Allowances and Certified Emission Reductions futures contracts. Section 2 details the data used in the study. Section 3 describes the different methodologies reported in the most relevant works in this line of research. Then, taking them into account, different return series are constructed. Section 4 studies if there are significant differences between the distributions of the different return series depending on the criterion applied. Section 5 repeats sections 3 and 4 for the transaction series. Section 6 summarizes the paper with some concluding remarks.

2. The Data

EUAs and CERs are the most important assets traded in the European Union Emissions Trading Scheme (EU ETS). Since 2005, many companies included in the 2003/87/CE Directive have the obligation to cover their real verified emissions with rights which allow them to emit one tonne of CO_2 or equivalent gas into the atmosphere. At the beginning of each year, each company receives entitlements (EUAs) to fulfill its requirements. Any excess or requirement of allowances can be trade off in the market. In addition, the 2004/101/CE Directive provides the opportunity to satisfy their hedge obligations with CERs, but only up to a determinate percentage, which varies amongst the different countries. Taken together, these two assets represent the base for any potential empirical study on carbon markets. For more details of the market, an excellent description of its particularities is presented in Mansanet-Bataller and Pardo (2008). Nevertheless, it is important to highlight that this market is divided into different phases, and because of their special characteristics, Phase I allowances cannot be used into Phase II. As a consequence, Phase I and Phase II allowances are two different assets.[1]

From its beginnings in April 2005, most of the derivative volume has been concentrated in the ICE ECX EUA Futures Contracts quoted in the ICE Futures Europe. This pattern is repeated with the ICE ECX CER Futures Contracts after their starts in March 2008. All in all, for our study we will concentrate on these futures contracts and in particular on those with maturity in December, being the ones which show higher volumes and a larger number of transactions. As an exception and because of being this contract being the last Phase I futures contract traded, we will also use the EUA Futures Contract with maturity in March 2008.

Our database is composed not only by all the available daily data for both EUAs and CERs Futures Contracts with maturity in December, but also March 2008 contract, from their start (April 22nd, 2005, and March 14th, 2008, for the EUAs and CERs Futures Contracts, respectively) to December 30th, 2011. Additionally and in order to obtain information related to the number of transactions, we have employed all the intraday data available, for all the futures contracts used. For each day the daily database contains the open, high, low and settlement prices (in Euros), the total volume (in lots) and the open interest (in lots). In addition, the intraday database contains for each trade the price (in Euros) and the transaction size (in lots).

[1] Phase I went from 2005 to 2007, Phase II is running from 2008 to 2012 and Phase III will cover 2013 to 2020.

3. Methodology

3.1. Rollover criteria

This section discusses 5 different criteria in order to determine the point in time when the switching from the maturing contract to the next one in order to link the series takes place. The first criterion is the "Delivery Day" or "Last Day" criterion (LD in tables). In this case, the switch occurs when the nearest contract expires. However, if abnormal volatility occurs in the sessions prior to the contract maturity, the researcher would construct a series with the maximum distortion.

The next 4 criteria seek the appropriate market liquidity conditions for the rollover. The rationale of these criteria is that if a trader was long or short in a futures contract and wished to hold it indefinitely, he would try to find the liquidity peak to switch the contract. The second criterion of "volume", defined as the number of contracts traded, (Vol in the following tables) implies the switching of the contract on the day when the volume of the first maturity is always lower than the volume of the second maturity.

The third "open interest" method (OI in tables) indicates the jump between series when the open interest of the second maturity is always bigger than the first one. The rationale behind this criterion is that many traders consider the open interest as a more reliable indicator of liquidity than volume. The reason is that high trading volume could be the result of closed positions and this would imply less liquidity in the market. In addition to this, we add a new criterion, the fourth one, which we call the "maximum open interest" (M.OI in the tables). In this case (and it is the only one) we allow jumping from one contract to another with a maturity different from the next-to-maturity contract that has the highest open interest until maturity.[2] By doing this, we can capture the particular behavior of the CO_2 futures markets and achieve some interesting conclusions.

The last criterion is based on the measure proposed by Lucia and Pardo (2010). In this case, the jump would occur on the day in which the number of closed positions is always larger than the number of opened positions for the nearby contract. This is, when the ratio $R3_t = \frac{O_t}{O_t + C_t} - \frac{C_t}{O_t + C_t}$ is less than zero until maturity, where $O_t = V_t + \Delta OI_t$ and $C_t = V_t - \Delta OI_t$, being O_t and C_t respectively the overall number of open and closed positions in the period *t*, while V_t and OI_t are the volume and the open interest of the period *t*. This methodology seeks to anticipate the fall of the open interest of the nearest maturity contract. With this criterion, the analyst avoids taking into account information on days in which the nearby contract has lost the interest of traders.

In the financial literature, there exists one additional criterion, the "Distortion free" methodology proposed by Geiss (1995). As it is pointed out by Saunier (2010), this criterion is not found to be adequate to run praxis-oriented tests. This method implies a continuous rebalancing each day due to the changing contract proportions. This would not be good enough for practitioners because the resultant series doesn't reveal the true prices quoted in the market and as a consequence investors could not use these prices in their investment strategies. For this reason, this last methodology is not included in our study.

Finally, it is important to highlight that the choice of the rollover date matters depending on what is being tested. For example, in some futures contracts the deferred months are more actively traded than the nearby ones. In these cases, the choice among

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[2] Applying this rule to volume or R3 does not produce a new series.

liquidity-seeking criteria is likely to be more reliable when constructing a continuous series of liquidity-related measures, such as volume or open interest.

3.2. Timing of rollover

Next, we consider how many days before the expiration date the rollover would be made effective by each of the 5 proposed methods. In the "last day" method, by definition, there are zero days between the contract expiration and the rollover date, and this would indicate that the last price with which the first maturity series contributes to the continuous series is the delivery price.

Concerning the methods based on the search of liquidity, we compute the days when the second contract volume or open interest values are persistently higher than those of the first one up to maturity. In order to construct a price series, we take prices from the contract with more volume or open interest, respectively. In the case of the "maximum open interest" we count the days when any contract systematically exhibits the maximum open interest until its expiration date, among all the existing contracts.

In the R3 criterion, the period computed ranges from the day when the R3 variable is negative up to the maturity day. This is, when the closed positions surpass the open ones in the expiring contract until the maturity day, both included. During those days, second contract prices replace the first ones.

Table I presents the mean and the standard deviation of the number of days between the rollover date and the front contract expiration date for the three assets considered: Phase I EUAs, Phase II EUAs, and Phase II CERs. In the case of the mean, this table informs about the average number of days before maturity, in which the information of the nearest contract is not used anymore in the construction of the long series. In the case of the "maximum open interest" criterion (M.OI), as this method allows jumping to the contract with the highest open interest, regardless of its maturity, this parameter cannot be calculated because data from several front contracts are not used for Phase II CERs and EUAs.

Note that the diverse criteria show results very different in terms of mean and standard deviation, especially in the case of Phase II EUAs and CERs, and therefore, the resultant constructed series will be expected to be quite divergent.

3.3. Percentage of data that differs between series

Table II displays the percentage differences on the number of data that varies between the different series. Now, the implications of Table I can be seen more clearly. Table II shows that the "maximum open interest" series are the most different in Phase II EUAs and Phase II CERs, followed by the "open interest" series for Phase II EUAs and CERs.

Table II shows that the "maximum open interest" and the "open interest" series are the most different both in Phase II EUAs and Phase II CERs.

This is because the open interest methodologies jump to the next contract far sooner than the rest of the criteria, as there is a contract with a later expiry date which dominates the remaining contracts in terms of OI. The rest of the series only vary up to 5.21% for the Phase I EUAs case, 1.17% for the Phase II EUAs series, and finally 4.62% for the Phase II CERs data.

Taking into account these results, the disparity in the number of data of each of the series could make it possible to work with different samples, taken from the same raw data. This is what we analyze in the following sections.

4. Empirical analysis

Before testing the equality of the distributions, it is important to clarify how to link the series of the different maturities. Note that when we switch from one contract to another, a jump in prices takes place. We correct this abnormal return by calculating the rollover day return as the log of the quotient between the closing price of the second maturity contract and the previous closing price of such maturity. Then, considering the return series calculated by making this adjustment only on the rollover day, we have tested the equality of means, medians and variances among the futures return series constructed following the 5 criteria explained in Section 3.

The equality of these parameters has been tested with the parametric Anova F-test, the non-parametric Kruskal-Wallis test and the Brown-Forsythe's statistic, respectively. The results are displayed in Table III. Panel A (Phase I EUAs), Panel B (Phase II EUAs) and Panel C (Phase II CERs) present similar results. The p-values indicate that it is not possible to reject the null hypothesis of equality of means, medians and variances in any case.

Therefore, independently of the method used to elaborate a unique and continuous future return series, we would reach the same conclusions in terms of means and variance. However, given that two series with the same parameters of position and dispersion could result in different distributions, we have applied the Wilcoxon/Mann-Whitney test, a non-parametric test based on ranks in order to determine if two groups (in this case series) have the same general distribution or not. The results of these tests are reported in Table IV. It can be shown that the null hypothesis of equality between distributions cannot be rejected in any case as all the p-values are far above 10%. Therefore, returns distributions of linked series are not conditioned by the criterion used to elaborate them.

5. Liquidity analysis

The previous analysis confirms the "last day" criterion as the simplest methodology to construct long futures return series. However, given that the rest of the methodologies are focused on different liquidity-seeking criteria, the question is: does the "last day" criterion offer appropriate market liquidity conditions?

To determine possible differences in market liquidity among the criteria, we have chosen the variable "number of transactions" (the number of agreements between a buyer and a seller to exchange any number of contracts for payment) as the most relevant due to the fact that a large number of transactions is indicative of high trading activity and this is directly related to market liquidity. Furthermore, it is interesting to highlight that given that this variable is based on intraday data, this part of the study could be of great interest for microstructure researchers. As high frequency data is not always easily at hand, this study would help researchers in their decision of choosing the most suitable rollover criterion, when their objective is to obtain the most representative series in terms of liquidity.

Firstly, following the steps described in Section 3, we have constructed the continuous transactions series. Then, we have carried out equality and distribution tests over the long series to determine possible significant differences among them in terms of liquidity. Table V presents the equality tests of means, medians and variances between the continuous transaction series, for Phase I EUA, Phase II EUA and Phase II CER, respectively.

The results of Table V are different for Phase I EUAs and for Phase II EUAs and CERs. In the first case, there are not significant differences among the long transactions series constructed, but in the second case, we reject the assumption of equality in terms of mean, median and standard deviation when we compare the five constructed series

(H0). This is due to the significantly lower level of transactions for the M.OI series. For these two assets, we take a second step and repeat the test, but now comparing all the series except M.OI. Again, we reject the hypothesis of equality of the analyzed parameters because of the OI series. Although OI series present a higher level of number of transactions than M.OI, it is not as high as in the rest of the methodologies. Finally, we repeat the tests for the rest of the transaction series constructed and no significant differences are found. Table VI confirms the previous results, giving evidence of the existence of significant differences in the transactions distribution for OI and M.OI and the rest of the series.[3]

Therefore, traders following "open interest" or "maximum open interest" rollover methodologies will face a more unfavorable intraday liquidity environment for the period considered, in both Phase II EUAs and Phase II CERs cases. This can be due to the fact that traders in Phase II EUAs and CERs maintain open positions in non-nearest-to-maturity futures contracts sooner than traders did in Phase I. The most striking case is the Phase II ICE ECX CER Futures Contract with maturity in December 2008 that began to be traded on March 14th, 2008. Only four trading days later, on March 20th, 2008, the open interest of the Phase II ICE ECX CER Futures Contract with maturity in December 2011 was higher than the open interest in the nearest-to-maturity futures contracts (December 2008).

Finally, it is worth noticing the results in the case of the "last day" method. This criterion offers the same level of transactions as the liquidity-seeking criteria and, as a

[3] These results are qualitatively similar to those obtained using other measures of trading activity as liquidity indicators. Specifically, we have repeated all the analysis in Section 5 by using both screen transactions and volume as trading activity measures. These results are available upon request from the authors.

consequence, this methodology grants a convenient liquidity frame to switch the contract or close the present position.

6. Summary and conclusions

The purpose of this study is to analyze the relevance of the choice of the rollover date when constructing continuous futures contract series in the ICE ECX futures market. The main methodologies related to the construction of long futures series have been revised, as well as the different adjustments to be made when linking them. One new criterion, “maximum open interest”, has been added to the previous literature accordingly with the specific futures contract analyzed. Therefore, five criteria have been applied to link all the EUAs and CERs futures contracts with maturities between April 22nd, 2005 and December 30th, 2011.

Our findings indicate that there are not significant discrepancies between the different continuous futures return series in terms of mean, median and variance. Identical conclusions are observed when comparing in pairs the general distribution among the different futures series. To sum up, the findings obtained here are consistent with Carchano and Pardo (2009) conclusions for the stock index futures. We confirm that the simplest methodology, which consists in jumping on the last trading day, can be used in order to reach the same results. A liquidity analysis gives robustness to this finding, given that the “last day” method offers the same level of transactions as the liquidity-seeking criteria. Therefore, in the case of EUAs and CERs futures contracts, the ease of construction of log return series is not at odds with the search for liquidity.

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Table I. Rollover timing for each criterion

This table indicates the mean and the standard deviation of the number of days between the rollover date and the expiration date of the contract for each of the 5 proposed methods. *LD, Vol, OI, M.OI, and R3* stand for last day, volume, open interest, maximum open interest, and R3 criteria, respectively. Sample period from April 22nd, 2005 to March 31st, 2008 for Phase I EUAs (Panel A), from April 22nd, 2005 to December 30th, 2011 for Phase II EUAs (Panel B), and from March 14th, 2008 to December 30th, 2011 for Phase II CERs (Panel C).

Panel A: Phase I EUAs	LD	Vol	OI	M.OI	R3
Mean	0.0	13.3	11.3	11.3	2.3
Std. Deviation	0.0	11.6	19.6	19.6	1.5

Panel B: Phase II EUAs	LD	Vol	OI	M.OI	R3
Mean	0.0	5.0	63.8	-	2.0
Std. Deviation	0.0	2.9	126.8	-	3.4

Panel C: Phase II CERs	LD	Vol	OI	M.OI	R3
Mean	0.0	9.5	114.5	-	3.5
Std. Deviation	0.0	10.3	99.5	-	4.5

Table II. Percentage data that differs between long futures return series

This table indicates the difference in percentage between the number of observations that is different when constructing continuous futures series following each criterion. *LD, Vol, OI, M.OI, and R3* stand for last day, volume, open interest, maximum open interest, and R3 criteria, respectively. Sample period from April 22nd, 2005 to March 31st, 2008 for Phase I EUAs (Panel A), from April 22nd, 2005 to December 30th, 2011 for Phase II EUAs (Panel B), and from March 14th, 2008 to December 30th, 2011 for Phase II CERs (Panel C).

Panel A: Phase I EUAs	LD	Vol	OI	M.OI
Vol	5.21%			
OI	4.01%	3.60%		
M.OI	4.01%	3.60%	0.00%	
R3	0.67%	4.54%	3.60%	3.60%

Panel B: Phase II EUAs	LD	Vol	OI	M.OI
Vol	1.17%			
OI	14.94%	15.64%		
M.OI	24.08%	24.66%	9.14%	
R3	0.47%	0.70%	15.29%	24.37%

Panel C: Phase II CERs	LD	Vol	OI	M.OI
Vol	3.83%			
OI	45.92%	42.09%		
M.OI	98.45%	96.28%	71.98%	
R3	1.45%	4.62%	44.88%	98.55%

Table III. Equality tests of long futures return series

Equality tests of means, medians and variances between the continuous return series constructed following the criteria explained in Section 3. *LD, Vol, OI, M.OI, and R3* stand for last day, volume, open interest, maximum open interest, and R3 criteria, respectively. The equality of means, medians and variances has been tested with the parametric Anova F-test, the non-parametric Kruskal-Wallis test and the Brown-Forsythe's statistic, respectively. The corresponding p-values appear in all panels at the end of the column. Sample period from April 22nd, 2005 to March 31st, 2008 for Phase I EUAs (Panel A), from April 22nd, 2005 to December 30th, 2011 for Phase II EUAs (Panel B), and from March 14th, 2008 to December 30th, 2011 for Phase II CERs (Panel C). H0 stands for the p-value of the equality tests of means, medians and variances between all the continuous return series constructed.

Panel A: Phase I EUAs	Mean	Median	Std. Deviation
LD	-0.009053	0.000000	0.120161
Vol	-0.009048	0.000000	0.120147
OI	-0.009013	0.000000	0.120177
M.OI	-0.009013	0.000000	0.120177
R3	-0.009042	0.000000	0.120162
H0	1.0000	1.0000	1.0000

Panel B: Phase II EUAs	Mean	Median	Std. Deviation
LD	-0.000573	0.000400	0.027361
Vol	-0.000576	0.000400	0.027361
OI	-0.000556	0.000400	0.027344
M.OI	-0.000565	0.000000	0.027327
R3	-0.000571	0.000400	0.027364
H0	1.0000	1.0000	1.0000

Panel C: Phase II CERs	Mean	Median	Std. Deviation
LD	-0.001311	0.000000	0.025804
Vol	-0.001334	0.000000	0.025826
OI	-0.001335	0.000000	0.025854
M.OI	-0.001356	0.000000	0.025695
R3	-0.001354	0.000000	0.025780
H0	1.0000	0.9999	1.0000

Table IV. Distribution tests of long futures return series

This table shows the p-values of the Wilcoxon/Mann-Whitney test that tests the null hypothesis that two continuous return series have the same general distribution. *LD, Vol, OI, M.OI, and R3* for last day, volume, open interest, maximum open interest, and R3 criteria, respectively. Sample period from April 22nd, 2005 to March 31st, 2008 for Phase I EUAs (Panel A), from April 22nd, 2005 to December 30th, 2011 for Phase II EUAs (Panel B), and from March 14th, 2008 to December 30th, 2011 for Phase II CERs (Panel C).

Panel A: Phase I EUAs	LD	Vol	OI	M.OI
Vol	0.9799			
OI	0.9966	0.9838		
M.OI	0.9966	0.9838	1.0000	
R3	0.9891	0.9914	0.9924	0.9924

Panel B: Phase II EUAs	LD	Vol	OI	M.OI
Vol	0.9931			
OI	0.9920	0.9854		
M.OI	0.9957	0.9973	0.9882	
R3	0.9991	0.9922	0.9928	0.9952

Panel C: Phase II CERs	LD	Vol	OI	M.OI
Vol	0.9846			
OI	0.9914	0.9945		
M.OI	0.8959	0.9101	0.9026	
R3	0.9628	0.9782	0.9703	0.9355

Table V. Equality tests of long futures transaction series

Equality tests of means, medians and variances between the continuous transaction series constructed following the criteria explained in Section 3. *LD, Vol, OI, M.OI, and R3* stand for last day, volume, open interest, maximum open interest, and R3 criteria, respectively. The equality of means, medians and variances has been tested with the parametric Anova F-test, the non-parametric Kruskal-Wallis test and the Brown-Forsythe's statistic, respectively. The corresponding p-values appear in all panels at the end of the column. Sample period from April 22nd, 2005 to March 31st, 2008 for Phase I EUAs (Panel A), from April 22nd, 2005 to December 30th, 2011 for Phase II EUAs (Panel B), and from March 14th, 2008 to December 30th, 2011 for Phase II CERs (Panel C). H0 stands for the p-value of the equality tests of means, medians and variances between all the continuous transaction series constructed. H1 stands for the p-value of the equality tests of means, medians and variances between all the continuous transaction series constructed except M.OI. H2 stands for the p-value of the equality tests of means, medians and variances between all the continuous transaction series constructed except OI and M.OI.

Panel A: Phase I EUAs	Mean	Median	Std. Deviation
LD	45.92719	36	46.66387
Vol	47.70877	39	47.09651
OI	46.40862	37	46.60285
M.OI	46.40862	37	46.60285
R3	46.23398	36	46.63303
H0	0.9683	0.9391	0.9991

Panel B: Phase II EUAs	Mean	Median	Std. Deviation
LD	665.8476	565.5000	643.4841
Vol	668.3810	574.0000	643.2869
OI	539.8628	371.0000	564.4725
M.OI	464.2176	273.0000	543.2803
R3	666.6706	569.5000	643.3162
H0	0.0000	0.0000	0.0000
H1	0.0000	0.0000	0.0000
H2	0.9931	0.9918	0.9999

Panel C: Phase II CERs	Mean	Median	Std. Deviation
LD	76.95114	60.00000	69.08475
Vol	77.56133	60.00000	70.52860
OI	69.02601	51.00000	68.91524
M.OI	48.57878	23.50000	71.24229
R3	77.09771	60.00000	69.18052
H0	0.0000	0.0000	0.4537
H1	0.0183	0.0000	0.9571
H2	0.9801	0.9985	0.9531

Table VI. Distribution tests of long futures transaction series

This table shows the p-values of the Wilcoxon/Mann-Whitney test that tests the null hypothesis that two continuous transaction series have the same general distribution. *LD, Vol, OI, M.OI, and R3* for last day, volume, open interest, maximum open interest, and R3 criteria, respectively. Sample period from April 22nd, 2005 to March 31st, 2008 for Phase I EUAs (Panel A), from April 22nd, 2005 to December 30th, 2011 for Phase II EUAs (Panel B), and from March 14th, 2008 to December 30th, 2011 for Phase II CERs (Panel C).

Panel A: Phase I EUAs	LD	Vol	OI	M.OI
Vol	0.3984			
OI	0.7727	0.5800		
M.OI	0.7727	0.5800	0.9999	
R3	0.8584	0.5026	0.9100	0.9100

Panel B: Phase II EUAs	LD	Vol	OI	M.OI
Vol	0.8998			
OI	0.0000	0.0000		
M.OI	0.0000	0.0000	0.0000	
R3	0.9667	0.9329	0.0000	0.0000

Panel C: Phase II CERs	LD	Vol	OI	M.OI
Vol	0.9954			
OI	0.0000	0.0000		
M.OI	0.0000	0.0000	0.0000	
R3	0.9593	0.9653	0.0000	0.0000

Chapter III

The Timeline of Trading Frictions in the European Carbon Market

1. Introduction

Market microstructure literature has shown that, at very short horizons, observable prices may temporarily differ from the "true" value because of trading frictions. These frictions are due to imperfections and limitations in the market regulation or the organization of trading. Trading frictions matter because they introduce noise into the price discovery process, make prices less informative, increase the costs of trading, and decrease liquidity.[1] According to microstructure literature, sources of frictions include price discreteness, market-making costs, temporary order imbalances, liquidity shortfalls, price smoothing rules, monopoly rents, etc.[2] The more important the friction-related component in price changes is, the less informative prices are and, therefore, the lower the market quality is.

In this paper, we study the history of trading frictions and market quality in the European carbon market. The EU Emission Trading Scheme (hereafter EU-ETS) handles the trading activity on European Union Allowances (EUAs), being the largest of its kind in the world, both in terms of volume traded and in terms of polluting installations covered. The EU-ETS is a cap-and-trade system, under which large emitters of carbon dioxide in the energy and industrial sectors must control and report their CO_2 emissions each year, and they are obliged to deliver to their corresponding governments an amount of EUAs that is equivalent to their emissions in that year. A EUA is an emission credit that gives the holder the right to emit one tonne of CO_2 or an equivalent amount of certain greenhouse gases. The installations covered by the EU-ETS received an initial endowment of emission credits through the National Allocation Plans (NAPs), until 2012. In Phase III, the assignment will be specified by the different

[1] Trading frictions are also relevant in asset pricing (e.g. Amihud and Mendelson, 1986, 1989).

[2] Excellent literature reviews on market microstructure research include O'Hara (1995), Hasbrouck (1996), Madhavan (2000), Harris (2003), Biais et al. (2005), and Hasbrouck (2007), among others.

sectors, considering Europe as a whole. Besides this initial allocation, emitters can purchase additional EUAs or sell their surplus of EUAs through financial markets. EUAs' trading is fragmented through electronic organized spot and derivative markets and also OTC markets. Among them, the European Climate Exchange (ECX), in London, is by far the most liquid pan-European platform for carbon emissions trading.

In this study, we consider the first two phases in the so far short history of the EU-ETS, Phase I, which covers emissions from 2005 to 2007, and Phase II, for emissions from 2008 to 2012. Phase I is generally considered a pilot or learning period (e.g., Ellerman and Buchner, 2006, and Creti et al., 2012, among others). Phase II concords with the Kyoto Protocol accomplishment period. A particularity of this scheme is that EUAs of Phase I could not be used to comply with the emission targets during Phase II (i.e., inter period *banking* was not allowed). Therefore, a EUA of Phase I is a different asset than a EUA of Phase II.

On May 15th, 2006, the European Commission released the official installation-level data for verified emissions and EUAs allocations for 2005. An apparent excess of emitted EUAs led to a large and sudden price drop in April 2006. Prices fell from 30€ to 10€ in a few days.[3] Continued rumors of excess supply, resulted in an early market collapse, with trading prices of 1.2€ by March 2007 and levels close to zero by September 2007. In addition to this market breakdown, the history of the EU-ETS is marked by the outbreak of the current international financial crisis. The deterioration of the real production expectations, inversely connected to the expectation of CO_2 emissions, had a severe negative effect on the EUAs prices by the beginning of 2009. In

[3] Ellerman and Buchner (2006) argue that earlier before these official statistics were revealed, observers recognized that the cap on CO_2 emissions was not very demanding. They therefore argue that the surprise that caused the drop in prices in April 2006 was not the excess of EUAs allocated, but an unexpectedly low level of emissions, either because they over-estimated the level of CO_2 emissions and the demand for allowances, or because they under-estimated the amount of abatement that would occur in the first year of the EU-ETS as the managers of affected facilities incorporated CO_2 prices into their production decisions.

this paper, we study whether the collapse of Phase I and the subsequent rash of the international financial crisis had a persistent negative effect on the market quality in Phase II, both in terms of higher friction-related components in prices, higher friction-related volatility, and lower liquidity.

The incidence of trading frictions in a financial market can be assessed in different ways. Some studies have established a negative link between trading frictions and liquidity supply, both in terms of higher immediacy costs and lower depth (e.g., Lee et al., 1993). Most of the literature, however, focuses on the bid-ask spread as a natural measure of trading frictions (see Stoll, 2000). Liquidity providers (such as market makers and limit-order traders) incur in different types of costs when providing liquidity. The bid-ask spread embodies the premiums and discounts the market makers demand to compensate the costs of immediacy (e.g., Demsetz, 1968). A substantial research effort has been devoted to the measurement of the theoretical components of the bid-ask spread.[4] It is usually distinguished between "real" frictions, such as inventory-holding costs (e.g., Ho and Stoll, 1983) and operative or order-processing costs (e.g., Roll, 1984), and "information-related" frictions, such as adverse selection costs (e.g., Glosten and Milgrom, 1985). Although the findings of this branch of the literature are not easily reconciled, they certainly show that both information-related and real frictions matter in explaining the size of the spread.

An alternative approach to deal with trading frictions is to decompose the variance of the price changes into its friction-related and information-related components. The higher the contribution of the friction-related volatility is, the lower the market quality is. In this case, the focus is on the deviation between the actual transaction prices and the unobservable underlying true value. Thus, a random walk

[4] See Glosten and Harris (1988); Stoll (1989); George et al. (1991); Lin et al. (1995); Huang and Stoll (1996); Madhavan et al. (1997), and Huang and Stoll (1997), among others.

specification may be highly satisfactory to describe the dynamics of prices sampled at low frequencies, such as weeks, months or quarters. At high frequencies (intraday data), however, returns are contaminated by microstructure noise, which leads to a random-walk-plus-noise representation, in which the friction-related component is transitory in nature. Madhavan et al. (1997) and Hasbrouck (1993) propose different methodologies to decompose the variance of transaction price returns. The former uses the estimated parameters of a structural model of price formation, whilst the latter proposes an econometric reduced-form approach.

In this paper, we employ a unique database with detailed information on all trades for the most frequently traded Phase I and Phase II EUA future contracts of the ECX market, including transaction data from April 2005 to December 2010. We apply three alternative microstructure approaches to measure trading frictions and price quality: (a) a simple and stylized structural-model based framework with or without adverse selection costs, derived from Roll (1984); (b) Madhavan et al. (1997) structural-model-based volatility decomposition, and (c) Hasbrouck (1993) reduced-form approach.

We find that during Phase I, excluding the 2007 market collapse, bid-ask spreads, relative spreads, adverse selection costs, market making profits per round-trip, price return volatility, and its friction-related components were all higher than during Phase II, all of these suggesting improved trading conditions during Phase II. However, the decomposition of the price return volatility provides a different picture. Summary measures of market quality suggested by our three methodological approaches coincide in showing that ECX achieved its lowest levels of quality during the 2007 market breakdown. They also agree that market quality progressively recovered during Phase II. In all cases, however, the market quality levels estimated by the end of our sample period are close but not better than those observed during Phase I before the market collapsed. Our findings therefore suggest that during most of Phase II, market quality has been recovering from the market breakdown at the end of Phase I and the additional negative impact of the international financial crisis. However, by the end of 2010, the recovery was incomplete.

This is not the first high frequency data analysis about the European Carbon Market. Using Phase I data on EUA futures, Benz and Hengelbrock (2008) compare ECX and NASDAQ OMX Commodities Europe in terms of liquidity and contribution to price discovery. Bredin et al. (2011) study the interaction between trading volume and price volatility during Phase I. Using 2008 data, Chevallier and Sevi (2011) characterize the conditional and unconditional distributions of realized volatility for ECX futures. Conrad et al. (2012) focus on modeling the dynamics of EUA prices from November 2006 to December 2008 using GARCH-type models. Mizrach (2012) provides evidence of common factors in prices for the European and North American emissions reduction instruments between June 2007 and April 2010. In a more related paper, Mizrach and Otsubo (2011) analyze spreads, price impact, and contribution to price discovery of both EUAs and CERs during 2009. Rittler (2012) studies causality between Phase II EUA spot and future prices for the period May 2008 to March 2009. Rotfuß (2009) deals with different issues about price formation and volatility in the EU-ETS from June 2005 to September 2008. Rotfuß et al. (2009) examine price reactions around the publication dates of the NAPs; their analysis cover between April 2005 and September 2008. Finally, Vinokur (2009) employs Phase I and Phase II EUAs and CERs spot data from BlueNext to analyze the impact of banking and submission constraints on price efficiency. Despite all this research effort, our paper offers the most complete and comprehensive high frequency analysis of liquidity, trading frictions, and market quality of the EU-ETS to date.

The remaining of the paper proceeds as follows. In section 2, we review the EU-ETS. In section 3, we describe the database and report some descriptive statistics. In section 4, we provide the methodological details. In section 5, we summarize our empirical findings. Finally, in section 6, we conclude.

2. Institutional details

2.1. The EU Emission Trading Scheme

The Kyoto Protocol, approved in December 1997, entered into force on February 16th, 2005, with the agreement of 141 countries. Linked to the United Nations Framework Convention on Climate Change (UNFCCC), this international agreement sets binding targets for reducing greenhouse gas emissions (henceforth, GHGE). Namely, by ratifying the Kyoto Protocol, industrialized countries commit to reduce their global GHGE by at least 5% (8% for the EU) against 1990 levels over the period 2008-2012. Because of the Kyoto Protocol, carbon trading has been growing continuously.

Although there were several prior experiences, the EU Emission Trading Scheme (EU-ETS) is nowadays the most important scheme for the issuance and trading of emission credits and derivative products. Established under the 2003/87/EC Directive, the EU-ETS officially started on January 1st, 2005 with the aim of regulating the carbon dioxide emissions for energy intensive installations across the EU, including combustion plants, oil refineries, coke ovens, iron and steel plants, factories making cement, glass, lime brick, tiles, pulp and paper, and other heavy industrial sectors. The emission credits distributed among the companies covered by the 2003/87/EC Directive are called European Union Allowances (EUAs). [5] The EU-ETS is a cap-and-trade system, meaning that total emissions are limited or 'capped'. Those installations/countries that succeed in reducing their emissions are more likely to act as sellers of emission credits. Those installations/countries that fail in complying with their emission targets are more likely to act as buyers of emission credits.

In order to neutralize irregular CO_2 emissions due to unexpected extreme weather events, such as harsh winters or very hot summers, EUAs are given out for a sequence of several years at once or "Phase". Phase I ended up on December 31st, 2007; Phase II coincides with the Kyoto Protocol commitment period, from January 1st, 2008 to December 31st 2012. There will be at least a Phase III, from January 1st, 2013 to December 31st, 2020. EUAs can be transferred between years within each phase. The "banking" facility allows participants to save surplus EUAs for being used during a later compliance period. The "borrowing" facility is just the opposite. Banking was not allowed from Phase I to Phase II, although it is permitted from Phase II to Phase III. Borrowing is forbidden in any case. This implies that a EUA of Phase I is a different asset than a EUA of Phase II.

Under the EU-ETS, each Member State prepared a National Allocation Plan (NAP), which establishes the national cap and its allocation among the installations covered by the 2003/87/EC Directive. The NAP had to be presented no later than 18 months before the start of each "Phase", and had to be approved by the European

[5] Other types of emission credits to be imported into the EU-ETS are fully fungible with EUAs. The 2004/101/EC Directive of the European Parliament (so called 'Linking Directive') allows EU members to use Kyoto certificates from the so-called "project-based flexible mechanisms" to cover their domestic greenhouse gas emissions. One of these flexible mechanisms is the Clean Development Mechanism. By developing an emissions-reduction project in a developing country, the EU country generates credits known as Certified Emissions Reductions (CERs) that can be used to meet its emissions targets under the Kyoto protocol. Each CER represents a successful emission reduction of one tonne of carbon dioxide. In this paper, however, we focus exclusively on EUAs.

Commission.[6] Accordingly, each Member State decided about how the emission credits are yearly allocated among the installations covered and about the possibility of banking and borrowing credits among phases. The allocation method in Phase III will differ: only one EU-wide emissions allocation will be elaborated, and each installation's individual allocation will be decided by the European Commission.[7] On an annual basis, each installation falling under the EU-ETS must surrender an amount of emission credits equivalent to its total emissions during the calendar year. An installation may therefore need to buy emission credits to cover actual emissions above its target. Failing to surrender the necessary emission credits will result in an excess emission penalty of (currently) €100/tonne (€40/tonne in Phase I). An installation emitting below its own cap can sell the excess of credits. The emission credits surrendered are immediately cancelled.

In Figure 1, we plot the time series of future prices for two contracts: EUA December 2007 futures contract and EUA December 2012 futures contract, as the representative futures prices for Phase I and II, respectively. Until April 24th, 2006, the future prices for Phase I EUAs and Phase II EUAs were pretty close. By this date, the Phase I EUA future price was about €31 and the Phase II EUA future price was €33.5, respectively.

As previously mentioned, Phase I was finally characterized by an over-allocation of EUAs which inevitably resulted in a dramatic fall in prices. Between April 25th and April 27th, The Netherlands, The Czech Republic, and France, all declared a surplus of EUAs, while Spain was less short than expected. As a consequence, rumors of over-allocation rose. From that date on, the spread between Phase I and Phase II future prices

[6] For further details, see Mansanet-Bataller and Pardo (2008).

[7] Between 2005 and 2007 (2008 and 2012) a minimum of 95% (90%) of the emissions were freely allocated. The other 5% (10%) was auctioned. In Phase III, auctions will play a more prominent role. By 2020, it is estimated that more than 60% of allowances will be auctioned.

progressively increased. By the end of April 2006, the Phase I (Phase II) EUA future price had decreased 54% (38%). By September 2006, the Phase I EUA prices experienced a second large drop. Prices fell steadily below €10. Two events marked this second drop: the weather and the crude oil price. Mansanet et al. (2007) find that EUAs' prices are affected by extreme temperatures. August 2009 was cooler and September 2009 was warmer than usual, decreasing the demand of energy and, therefore, the demand of EUAs. Besides, the crude oil price fell below US$60. The most emission intensive energy source is coal, followed by oil and then gas. The oil price drop depressed the demand of coal and, therefore, the demand of EUAs. An unusually warm and wet 2006 autumn, and the increasingly restrictive conditions to carry-over unused allowances from Phase I to Phase II (banking), declined even more EUAs prices. At the end of 2006, the Phase I future price was €6.6, while the Phase II future price remained close to €20.

In general, the 2006 total emissions overpassed those of 2005, but many EU Members were still long in allowances. Rumors of over-allocation continued and prices experienced a definitive drop. On February 19th, 2007, Phase I EUAs were priced below €1 for the first time. On May 14th, 2007, 8 months before their expiry date, the price of a December 2007 future contract on Phase I EUAs was below €0.33. At that date, Phase II EUA future price started a progressive increase, achieving its maximum on July 1st, 2008, €34.38 per CO_2 tonne. The appreciation of the Phase II EUAs is the result of the approval by the European Commission of more conservative NAPs for Phase II. Determined to avoid history repeating, the European Commission imposed severe cuttings over the initial Members' proposals. Moreover, the crude oil price was steadily increasing by that time.

Phase II prices were severely affected by the international crisis and the consequent downward revision in the real production expectations, directly connected with the expected CO_2 emissions. On February 12nd, 2009, EUA future price was €9.43, the historical minimum in Phase II. As was indicated in *Tendance Carbone* (February 2009, 33, p.1), the monthly bulletin of the European Carbon Market, "Our European temperature indicator was almost 3° below its ten-year average in January [2009]. Such an anomaly would normally boost demand for electricity and heat, which in turn tends to increase the price of CO_2. However, this factor was more than offset by the economy's recession. […] Experience shows that in a recession, CO_2 emissions exhibit elasticity greater than one relative to GDP". Since February 2009, the future price of the EUA has fluctuated around €15 per tonne.

Trading activity in the EU-ETS is purely electronic. Each Member State has its own account where the balance of the allowances of each installation is captured. Trading activity, however, is not restricted to the companies affected by the 2003/87/CE Directive. To guarantee additional sources of liquidity, external agents are allowed to trade too. To participate, however, they may have a trading account in the corresponding market. As the European Commission does not preclude each EU member from having its own trading platform, trading of carbon-related assets is fragmented through different markets around Europe.[8] From 2005 to 2007, spot trades

[8] Spot markets include BlueNext (París), which is part of NYSE-Euronext since December 2007, Energy Exchange of Austria (Vienna), NASDAQ OMX Commodities Europe (Oslo), European Energy Exchange (EEX, Leipzig), European Climate Exchange (ECX, London), only in Phase II, and Gestore Mercato Elettrico (Rome). Future markets on EUAs include European Climate Exchange (ECX, London), NASDAQ OMX Commodities Europe, EEX, and BlueNext only in Phase II. Options on EUAs are also traded in some of the previous markets, such as ECX.

of Phase II EUAs were not possible; futures on Phase I and Phase II EUAs, however, were both simultaneously traded.[9]

Table I provides statistics on total trading volume in lots (1,000 tonnes of CO_2 equivalent) and market shares for the most representative markets in the EU-ETS. Panel A (B) of Table I reports statistics on the spot (futures) market for EUAs. Table I shows that most of the trading activity of EUAs concentrates on the futures markets. BlueNext has historically dominated the spot market. Nonetheless, its market share has decreased from 100% in 2008, beginning of Phase II, to 54.7% at the end of 2010. The ECX EUA Daily Futures Contract ("spot") was introduced in March 2009. In two years, the ECX spot market reached a 39.5% market share. Regarding the derivatives market, ECX clearly dominates, with yearly market shares permanently above 96%. In this paper, we will focus exclusively on the futures market of ECX.

2.2. The microstructure of the European Climate Exchange (ECX)

ECX is a member of the Climate Exchange Plc group, listed on the AIM market of the London Stock Exchange. ECX future contracts are operated by the Intercontinental Exchange (ICE) Futures Europe, one of the leading markets in the negotiation of energy derivatives in Europe. Trading on ICE ECX contracts is handled either by the ICE Electronic Platform, for ordinary trades, the Block Trade Facility, for bilateral transactions of large size (minimum 50 lots), or the Exchange of Futures for Physicals/Swaps (EFP and EFS), to transfer an OTC position to an on-exchange futures position. Members of the ICE Futures Europe enabled for ECX contracts can operate on their own account only ('Trade Participant') or also on behalf of their clients ('General

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[9] The first spot trade for Phase II EUAs took place in BlueNext on February 28th, 2008. The first spot (future) trade on an organized market on EUAs took place on March 8th, 2005 (February 11th, 2005) in EEX (NASDAQ OMX Commodities Europe).

Participant'). Trading may also be conducted by a Member's clients ('order routing') where the access to the ICE Platform is granted by the Member.

The ICE Platform daily session starts with a pre-open period of 15 minutes (from 6:45 a.m. UK local time) during which traders can submit, modify and cancel limit orders, but market orders are not allowed. The limit order book is not displayed during this period, but the market reports tentative allocation prices. The pre-opening period ends up with a so-called "opening match", a single call auction, where the opening price and the allocated volume are determined by an algorithm. No new orders are allowed during the opening match.

During the continuous session, from 7:00 a.m. to 5:00 p.m., investors can submit limit orders (default type), which are stored in an electronic limit order book (hereafter LOB) following strict price-time priority criteria, market orders, and block orders.[10] Stop orders were also introduced in January 2008. Limit orders can be modified (in price or volume) or withdrawn from the LOB. By default, standing limit orders expire at the end of a trading session. The contracts are traded in lots. Each lot equals to 1,000 tonnes of CO_2 equivalent, that is, 1,000 EUAs. The quotation is in Euros per lot and the minimum tick size for all contracts is €0.01.[11]

As transparency regards, ECX offers real-time prices through the market screens and the major information and data vendors. The LOB is open during the continuous session. All orders entered and the resulting executed trades, however, are anonymous. Iceberg orders are allowed, which means that the trader may choose not to display the full size of their limit orders. The unrevealed part of the order is released only when the

[10] Before January 9th, 2006, the continuous session ran between 08:00 a.m. and 5:00 p.m.

[11] Before March 27th, 2007, the tick size was €0.05.

first part of such order is completely filled. The unveiled part of the iceberg order loses time priority.

A trade happens in the ICE Platform when two orders of opposite sign for the same contract and expiry date match. Matching happens when the price of the bid (offer) order equals or is greater (lesser) than the price of the offer (bid). Dynamic price limits computed from the prior transaction price are activated during the continuous session. When these limits are reached, the order that caused the limit hit ceases executing and the remaining volume of the order is cancelled.

Since 2005, ECX has invited Members to act as market makers for the future contracts on EUAs. However, the first two market makers were announced on July 24th, 2007. The market maker programs extend for periods of 3 to 6 (extensible) months, and the positions are limited to a maximum of 3 to 5 market makers per contract. Market makers must ensure, on a daily basis, that the spread is not wider than a predetermined amount. For December contracts the minimum spread is either €0.05, €0.08, €0.15 or €0.20 depending on the time the program is announced (it tends to decrease from Phase I to Phase II) and the contract expiry (it is smaller for contracts with close expiry). Market makers must also guarantee a minimum depth of 10 lots on both sides of the book, and they must make the market for at least 85% of the duration of the continuous session.

2.3. The ICE ECX EUA futures contracts

In general, Phase I and Phase II ICE ECX EUA futures are listed on a quarterly expiry cycle, with March, June, September and December contracts up to 2012. The first ICE ECX future contract was issued on April 22nd, 2005, with expiry in December

2005.[12] The contracts are physically delivered by transfer of EUAs. Daily settlement prices are obtained as the trade weighted average of transaction prices during the closing period (4:50 – 5:00 p.m.) as long as a minimum volume is achieved.[13]

In Table II, we report some summary statistics on the trading activity of the different ECX EUA future contracts, both from Phase I and Phase II. Table II shows that EUA future contracts with December expiry concentrate most of the trading activity of the ECX market in both phases. From a total of 980,738 trades on EUA futures of Phase I and Phase II between April 2005 and December 2010, 99.41% were on the December contracts. In terms of volume traded, December contracts account about 97.7% of the accumulated volume (in lots) of Phase I and Phase II (10,467,264). Similar figures are obtained for Phase I and Phase II separately: 98.34% of trades and 95.7% of volume for Phase I and 99.99% of trades and 99.98% of volume for Phase II.

Figure 2 reports the accumulated volume (in millions of lots) through time of the EUA future contracts with expiry date in December 2005 to 2012. This figure shows that trading volume generally concentrates on the December contract closest to expiry. The notable exception is the December 2007 future contract, surpassed by the December 2008 contract early in 2007, the last year of Phase I. Figure 2 also shows that ECX trading activity has increased overtime.

3. The database

In our empirical analysis, we use high frequency data provided by ECX covering all Phase I (from April 22nd, 2005 to December 17th, 2007) and part of the current Phase

[12] The first EUA daily futures contract or "spot" contract was issued on March 13th, 2009. We will ignore the spot market in this paper because of this late start.

[13] For further details on the EUA future contracts, see the ICE ECX user's guide: https://www.theice.com/publicdocs/ICE_ECX_user_guide.pdf. Last access on December 1st, 2011.

II (from April 22nd, 2005 until December 31st, 2010) of the EU-ETS. Our database consists of all trades registered in ECX during our sample period for all future contracts. For each trade, the database contains the price, the size (in lots), the sign (i.e., whether it is buyer or seller-initiated), the trade type, and the time stamp (to the nearest hundredth of a second). We consider only “screen” (ordinary) trades from the continuous session; we ignore the pre-opening period.

Table III provides some sample descriptive statistics per contract. Panel A of Table III provides price statistics and aggregate trading and trade-size statistics. Given previous tables and figures in this paper, it should not come as a surprise that trading activity increases from the December 2005 future to the December 2010 future, from Phase I to Phase II contracts in general, and that the December 2007 future experiences the lowest price and highest standard deviation of transaction prices. Panel B of Table III reports trade-related statistics. Notice that even though all Phase I and Phase II EUA future contracts were issued on the same day (April 22nd, 2005), Phase II futures took several months to generate the first trade. December 2008, 2009, and 2010 (Phase II) future contracts are the most frequently traded in our sample, with one trade in average every 2 to 3 minutes.

In addition, Table III reports statistics on two continuous time series obtained by rolling over the time series of the finite-life future contracts negotiated in ECX. In this way, we generate a single time series representing EUA future prices and trades for each EU-ETS phase. We use the maximum volume criterion in order to rollover the series.[14] According to this criterion, we switch contracts when the front contract is no longer the most negotiated systematically. Table IV provides details on the rollover

[14] Following Carchano et al. (2012), the distribution properties of the resulting time series, considering alternative rollover criteria, are not affected by the rollover selection, reason why we decided to use the maximum volume criterion, as the one which guarantees the most traded time series in terms of volume.

dates, that is, the points in time when we switch from the front contract series to the next one, for each EU-ETS phase. Our Phase I time series covers from April 22nd, 2005 to December 17th, 2007.[15] Phase II time series covers from June 17th, 2005 to December 31st, 2010. These time series for Phase I and Phase II are the main input of our posterior analysis.

Table V provides statistics on the different types of trades available for our study. Panel A of Table V shows that regular screen-based trades are by far the most extended, representing 63.1% of Phase I future trades and 83.53% of Phase II future trades. Panel B shows that in terms of volume traded, however, their weight decreases to 44.54% for Phase I future trades and 51.85% of Phase II future trades, suggesting that the average size of screen trades is smaller than that of other less ordinary trades, such as Exchange of Futures for Physical/Exchange of Futures for Swaps (EFP/EFS) trades. EFP/EFS trades in Phase I (Phase II) represent 34.29% (13.15%) of future trades, but they account for 53% (45.4%) of volume traded. Unfortunately, EFP/EFS trade data do not contain the trade direction, information we need to apply the methodologies described in the next section. Therefore, we discard them from our empirical analysis. As Table V shows, the other categories of trades are of minor relevance.

All time series used in this paper are corrected for reporting errors, confirmed by ECX staff members. In computing return series, overnight returns are also eliminated. Returns are calculated using trade prices in logs.

[15] As indicated by the 2003/87/EC Directive, member states must cancel the EUAs that are no longer valid. Moreover, companies must surrender the allowances of a given year no later than April 30th of the next year. Thus, Phase I EUAs were no longer valid after May 2008 and were cancelled by April 30th, 2008. We exclude, however, all trades during 2008, because they were scarce and spaced.

4. Measuring trading frictions and market quality

Since ECX quote and limit order book data is not available, our analysis of trading frictions and market quality in the history of ECX relies on methodologies based exclusively on trade data. In this section, we briefly review these methodologies. For more details, we redirect the interested reader to the original papers.[16]

As previously discussed, some authors understand trading frictions as the concession needed for an immediate transaction, that is, the price of immediacy (e.g., Stoll, 2000). The bid-ask spread is the most commonly used proxy for immediacy costs, a generally accepted dimension of liquidity (e.g., O'Hara, 1995). Nowadays, data on at least the best ask and bid quotes are available for all major financial markets. In the 70's and 80's, however, researchers had only access to trade prices. In this context, Roll (1984) developed a methodology to estimate an implicit bid-ask spread using the covariance of transaction returns.

Define the efficient price (m_t) as the expectation about the true value of the asset at some terminal time given the information that is publicly available, i.e., $m_t = E\left(\Im_T \middle| \Phi_t\right)$. This expectation only changes when new information arrives at the marketplace, which means that changes in m_t are unpredictable. Thus, m_t is generally assumed to follow a random-walk process, $m_t = m_{t-1} + \eta_t$, where η_t is an information-related white-noise innovation with $\eta_t : iid\left(0, \sigma_\eta^2\right)$. In a frictionless market, the actual trade prices (p_t) are always equal to m_t.

[16] Most of the discussion that follows is based on seminal structural models of price formation such as Roll (1984), Glosten and Harris (1988), Stoll (1989), and Madhavan et al. (1997). For comprehensive reviews of these models and the concepts involved see Hasbrouck (1996, 2007), Huang and Stoll (1997), and de Jong and Rindi (2009).

Roll (1984) assumes a world without information asymmetries, where the trading process conveys no information. Trading frictions are captured by a constant bid-ask spread entirely due to real frictions, to be precise, market makers' order-processing costs. Additionally, Roll (1984) assumes that all trades are with the market maker; all trades are of equal size (unitary); buys and sells are equally likely, and the trading process is serially uncorrelated. Because of the constant bid-ask spread, transactions happen at either the ask or the bid quote, not at m_t. This so-called 'bid-ask bounce' effect generates negative serial correlation in the changes in transaction prices. To see this, consider that $p_t = m_t + (S/2)x_t$, where *S* is the constant bid-ask spread and x_t is the trade indicator, which equals 1 for buyer-initiated trades and -1 for seller-initiated trades. Under the Roll (1984) assumptions,

$$Cov_{\Delta p} = Cov(\Delta p_t, \Delta p_{t-1}) = E[\Delta p_t \Delta p_{t-1}] = \frac{-S^2}{4}. \tag{1}$$

The Roll's bid-ask spread estimator *S* can be obtained from the serial covariance of price changes and (1).[17] Alternatively, given that

$$\Delta p_t = (S/2)(x_t - x_{t-1}) + \eta_t, \tag{2}$$

S can be obtained as 2 times the estimated a_1 coefficient of the regression equation $\Delta p_t = a_0 + a_1 \Delta x_t + e_t$, with expected values $a_0 = 0$, $a_1 = S/2$, and $Var[e_t] = \sigma_\eta^2$. Finally, from (2), we can decompose the variance of Δp_t into a friction-related and an information-related component, $Var(\Delta p_t) = \sigma_\eta^2 + 0.5S^2$, implying that the Roll's measure of the quality of prices is given by $Q^R = \sigma_\eta^2 / (\sigma_\eta^2 + 0.5S^2)$.

[17] Because by assumption x_t and η_t are serially uncorrelated, the negative correlation in (1) is entirely friction-related, due to the bid-ask bounce.

Roll (1984) stylized framework assumes that there are no information asymmetries in the market. Instead, suppose that the innovation to m_t can be decomposed as $\eta_t = \alpha\left(S/2\right)x_t + u_t$, where u_t is an innovation due to public news, and α is the adverse selection costs parameter. Let $E\left[x_{t-i}u_{t-j}\right] = 0,\ \forall i, j$, so that there are two sources of information, trade-related (private) and trade-unrelated (public) news. Besides, there are no lagged effects of trades on prices, and signed trades are serially uncorrelated or $\Pr\left(x_t \neq x_{t-1} \mid \Phi_{t-1}\right) = \pi = 1/2$. With the additional assumption that quotes are ex-post rational, as in Glosten and Milgrom (1985), $p_t = q_t + \left(S/2\right)x_t$, where $q_t = m_{t-1} + u_t$ is the quote midpoint. With this price decomposition, $\alpha\left(S/2\right)$ and $\left(1-\alpha\right)S/2$ are the adverse selection costs component and the real friction component of the spread, respectively. Given that,

$$\Delta p_t = \left(S/2\right)x_t - \left(1-\alpha\right)\left(S/2\right)x_{t-1} + u_t, \tag{3}$$

the relevant parameters can be recovered from the estimated coefficients of the regression equation $\Delta p_t = b_0 + b_1 x_t + b_2 x_{t-1} + e_t$, where expected values are $b_0 = 0$, $b_1 = S/2$, $b_2 = -\left(1-\alpha\right)\left(S/2\right)$ and $Var\left[e\right] = \sigma_u^2$. From (3), $Cov_{\Delta p} = -\left(1-\alpha\right)^{-0.5} 0.25S^2$, meaning that Roll's bid-ask spread estimator underestimates the true spread whenever α > 0. Regarding quote quality, the variance of Δp_t in (3) is

$$Var\left(\Delta p_t\right) = \sigma_u^2 + 0.25S^2\left[2\left(1-\alpha\right) + \alpha^2\right]. \tag{4}$$

The second RHS term of (4) is friction-related. Because $Var\left(\Delta m_t\right) = \sigma_u^2 + 0.25S^2\alpha^2$, it turns out that $0.5S^2\left(1-\alpha\right)$ is the only fraction of (4) that is transitory (i.e., noisy) in nature. From (4) we can see that, unless α = 0, Q^R overestimates the quality of prices, which is given by $Q^A = \sigma_u^2 / Var(\Delta p_t)$.

Another interesting measure that can be obtained from the former price decomposition is the expected realized spread. It measures the expected gains of the liquidity provider after a roundtrip, and it is given by

$$E(S^r) = E(\Delta p_t \mid x_{t-1} = -1) - E(\Delta p_{t+1} \mid x_t = 1). \qquad (5)$$

In a frictionless market, the expected realized spread equals S. Under our simple adverse selection costs model $E(S^r) = (1-\alpha)S$, that is, the market makers expect to realize the part of the quoted spread, which is not lost with informed traders.

As previously mentioned, Roll (1984) assumes no serial correlation in trades. Empirical studies, however, show the trade indicator is serially correlated, that is, $\pi \neq 1/2$.[18] Under this condition, $E[x_t x_{t-1}] = 1 - 2\pi$ and $E[x_t | x_{t-1}] = (1-2\pi)x_{t-1}$. Choi et al. (1988) showed that, with serial correlation in trade signs, $Cov_{\Delta p} = -\pi S^2$. Therefore, if $\pi < 1/2$, Roll's estimate of the bid-ask spread in (1) underestimates the true spread. Moreover, $Var(\Delta p_t) = \sigma_\eta^2 + \pi S^2$; thus, if $\pi < 1/2$, Q^R overestimates the quality of prices. If we allow for both adverse selection costs and serial correlation in trades, it is straightforward to prove that $Var(\Delta p_t) = \sigma_u^2 + 0.25S^2 \left[4\pi(1-\alpha) + \alpha^2\right]$, and $E(S^r) = S(2\pi - \alpha)$. So, the higher the probability of a trade reversal, the higher the transitory component in the volatility of prices and the higher the expected realized spread.

[18] Serial correlation in trade sign may arise because of imitative or 'herding' behavior by traders; traders splitting large orders into smaller ones (stealth trading), different traders reacting progressively to the same information (e.g., Hasbrouck, 1996).

In the prior adverse selection costs version of Roll's model, we have assumed that the efficient price depends on x_t. However, as long as $\pi \neq 1/2$, there is a predictable component in x_t which, by definition, does not convey information. Let $w_t = x_t - E\left[x_t \middle| x_{t-1}\right]$ be the unexpected component in the trading process. By assuming that $\eta_t = \theta w_t + u_t$, only the unexpected trade-related component (w_t), has an effect on the efficient price. In this case, θ is the adverse selection costs parameter, and $u_t : iid(0,\sigma_u^2)$ is a public information innovation. Now, let ϕ be the market making costs parameter covering real frictions; by further assuming ex-post rational ask and bid quotes, $p_t = m_t + \phi x_t + \xi_t$, where $\xi_t : iid(0,\sigma_\xi^2)$ is an innovation that accounts for rounding errors and price discreteness.[19] Under the prior assumptions, Madhavan et al. (1997) show that $\Delta p_t = (\theta + \phi)x_t - (\rho\theta + \phi)x_{t-1} + \varepsilon_t + \xi_t - \xi_{t-1}$, where ρ is the first order autocorrelation the trading process, that is, $\rho = E(x_t x_{t-1})/Var(x_{t-1}) = 1 - 2\pi$. Thus,

$$Var(\Delta p_t) = \sigma_u^2 + 2\sigma_\xi^2 + (\theta + \phi)^2 + (\rho\theta + \phi)^2 - 2(\rho\theta + \phi)(\theta + \phi)\rho. \quad (6)$$

From expression (6), the variance of price changes can be decomposed into the following terms: $2\sigma_\xi^2$, due to price discreteness; $(1-\rho^2)\theta^2$, due to adverse selection costs; $2(1-\rho)\phi^2$, due to real frictions, and $2\phi\theta(1-\rho^2)$, an interaction term.[20] In this model, our measure of quality of prices is given by $Q^{MRR} = \sigma_u^2 / Var(\Delta p_t)$, where $Var(\Delta p_t)$ is given by (6). Finally, under the assumption that $w_{t-1} = -1$ and $w_t = 1$, the expected realized spread is $E(S^r) = 2\left[2\pi(\phi + \theta) - \phi\right]$. Madhavan et al. (1997) suggest

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[19] The parameter θ can be seen as α(S/2) and ϕ as (1-α) (S/2), so that the implicit spread S = 2(θ + ϕ).

[20] In Madhavan et al.'s (1997) original model specification, the authors account for the possibility of transaction prices within the spread (price improvements). In the ECX futures market, price improvements are not possible, so we simplify the model accordingly.

estimating the model parameters $\left\{\theta, \rho, \phi, \sigma_u^2, \sigma_\xi^2\right\}$ using the generalized method of moments (GMM).

As an alternative to the structural-model-based approach described so far, Hasbrouck (1993) proposes an econometric reduced-form approach to evaluate the quality of prices. He considers a very general price decomposition model, $p_t = m_t + s_t$, where s_t is the pricing error, which impounds information-uncorrelated microstructure effects. This pricing error is assumed to be a zero-mean covariance-stationary stochastic process. Hasbrouck proposes the standard deviation of the pricing error (σ_s) as a summary measure of market quality, as it captures how closely the transaction price tracks the efficient price. The variance of log transaction prices (σ_p^2) is decomposed into the variance of the efficient price (σ_m^2) and σ_s^2 by means of inverting a vector autoregressive (VAR) model for transaction prices and trade-related information (i.e., trade sign and size). Following Boehmer et al. (2005), we use the ratio σ_s / σ_p as a relative measure of market quality.[21] Because of its general dynamic specification, the VAR model accounts for the lagged effects from trades to prices and vice versa. In order to identify s_t, however, Hasbrouck needs to impose identification restrictions *a la* Beveridge and Nelson (1981), the main implication being that only a lower bound for σ_s^2 can be obtained.

Following Hasbrouck (1993), we estimate a VAR model in trade time over the variable set $\left\{r_t, x_t, x_t^s, x_t^{s1/2}\right\}$, where r_t is the continuously compound return, the first difference in the log trade price; x_t is the previously defined trade indicator; x_t^s is the

[21] Boehmer et al. (2005) use Hasbrouck (1993) methodology to analyze the impact on market quality of the increase in pre-trade transparency that came about in the NYSE after the introduction of the OpenBook in January 2002.

signed trade size (in shares), and $x_t^{s1/2}$ is the signed square root of the trade size. The use of various powers of the signed trade size is intended to capture non-linearities in both m_t and s_t.[22] The VAR model is truncated at 3 lags.[23]

5. Empirical findings

We apply the statistical methods described in the previous section to the Phase I and Phase II future contracts time series. The analysis is performed for each calendar quarter between July 2005 and December 2010. In Table VI, we provide trading activity statistics per quarter. Exceptionally, the first and last "quarters" of Phase I cover more than 3 months of data: from January 1st, 2005 to September 30th, 2005 and from July 1st, 2007 to December 17th, 2007, respectively. We join up transactions from different calendar quarters so as to have enough observations to apply the statistical methods. During the first semester of 2005, there were only 560 trades in ECX; during the last two quarters of Phase I there were only 182 and 319 trades, respectively. Similarly, future contracts on Phase II EUAs were thinly traded up to the last calendar quarter of 2006 (only 989 transactions). Thus, the 3,349 trades reported for the Phase II future contracts on the last quarter of 2006 include all trades since April 2005.

During Phase I, there was a median of 2,116 trades per quarter, with a minimum of 501 trades (last quarter of 2007) and a maximum of 3,966 (second quarter of 2006). For Phase II EUA future contracts, the median trades per quarter were 7,834, with a minimum of 3,349 (first quarter considered) and a maximum of 105,584 (second quarter

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[22] For details on the VAR specification, the vector moving average (VMA) representation of the VAR model, and the specific expressions for computing both σ_m and σ_s from the estimated coefficients of the VMA representations, see Hasbrouck (1993, p. 201-202). These technical details are omitted for brevity.

[23] We have also considered time series models truncated at 5 lags. Our main findings are basically the same.

of 2010). The median volume traded per quarter for Phase I future contract series was 17,867 lots, while it was 57,428 lots for Phase II series. The median net volume (buyer-initiated minus seller-initiated) per quarter was negative (-1,171 lots) in Phase I and positive (3,466 lots) in Phase II.

In Table VII, we report the estimates of Roll's (1984) structural model of price formation. We show the estimates of the model with and without information asymmetries. In Panel A (B) of Table VII, we report the findings for Phase I (II) EUA futures. In Panel C, we include a regression-based estimate of the average slope of the trend of each quarterly time series, and several non-parametric tests for the equality of medians across phases and sub-periods.[24]

The structural model without information asymmetries reports a median estimated bid-ask spread (*S*) of 0.0472€ for future contracts on Phase I EUAs, with a maximum of 0.11€ in the second quarter of 2006, coinciding with the first large drop in Phase I future prices. For futures on Phase II EUAs, the median estimated bid-ask spread was 0.0404€ during Phase I period and 0.0160€ during Phase II period. The negative slopes in the *S* trend for Phase II EUA futures, during both Phase I and Phase II periods, are corroborated by the statistical tests in Panel C. During Phase I, *S* was statistically higher than during Phase II, even when we exclude the 2007 collapse. For example, the median difference in *S* between Phase I before the collapse and the beginning of Phase II (2008) was 0.0363€, but it increases to a median of 0.0491€ if all Phase II is considered.

[24] The average trend is obtained by fitting a deterministic time polynomial to each quarterly time-series, that is, $y_t = a_0 + a_1 t + \varepsilon_t$, using robust regression to account for outliers. Table VII, Panel C, reports the estimated a_1 coefficient. We use the non-parametric Mann-Whitney U-test for small samples to test for differences in medians.

To obtain an estimate of the relative spread at each quarter, we use price returns instead of price changes in estimating the structural model parameters. From Panel A of Table VII, the median relative spread before the April 2006 price drop was about 0.32%. The market collapse led to relative spreads of 13.68% by the end of 2007. For Phase II EUAs futures, during Phase I the median relative spread was 0.2%, 0.13% during 2008 and 0.06% by the end of 2010. The maximum relative spread of Phase II, 0.25%, was achieved during the first quarter of 2009.[25] Statistical tests in Panel C confirm that the relative spread was higher during Phase I, even before the collapse, than during Phase II (both during 2008 and after 2008). The median difference between both phases was 0.36%.

The structural Roll model with information asymmetries provides additional insights. The estimated bid-ask spread (*S*) follows a similar temporal pattern than in the previous model. As expected, however, *S* estimates are generally higher, as the original Roll (1984) estimator underestimates the true spread in the presence of information asymmetries. The median *S* for Phase I EUA futures was 0.0675€, and for Phase II EUA futures was 0.0347€ during Phase I and 0.0186€ during Phase II. Regarding the estimated adverse selection costs parameter (α), for Phase I EUA futures α decreased from a global maximum of 65.2% of the spread the third quarter of 2005 to a global minimum of 17.5% of the spread two years later, when the price of the Phase I EUA was almost zero. Phase II EUA futures achieved its maximum α, about 50%, the last quarter of 2006; afterwards, α decreased to 38.6% at the end of Phase I. During Phase II, α was stable, about 30% of the spread. Statistical tests in Panel C of Table VII show

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[25] The peak in both bid-ask spreads and relative spreads during the first quarter of 2009 is probably due to the liquidity shortage generated by the financial crisis. In January 2009, firms were able to predict their EUAs requirements for 2008 quite precisely. In April 2009, they had to deliver the EUAs needed to cover their 2008 emissions, and in February 2009, they were expecting their 2009 EUAs allocation. So, many firms sold their expected surplus of EUAs to get cash and bought December futures on EUAs to hedge this short position, leading to the increase in immediacy costs.

a significant median difference in α of about 18% between phases, but no remarkable variations between different sub-periods of Phase II.

Figure 3 plots the resulting adverse selection costs (hereafter ASC), as given by αS, for Phase I and Phase II EUA futures. ASC for Phase I EUA futures decreased from 0.088€ per one lot round-trip during the third quarter of 2005 to 0.0017€ at the end of Phase I. In the second quarter of 2006, a period with high uncertainty about the true value of the asset, ASC increased to 0.0862€. Regarding Phase II EUA futures during Phase I, median ASC were about 0.0231€; during Phase II, however, they fell to 0.0053€. The statistical tests in Panel C of Table VII, confirm: (a) the downward slopes of the ASC curves in Figure 3; (b) the higher costs during Phase I, with a median difference of 0.0353€ (ranksum test p-value, 0.0001); (c) the higher costs for Phase II EUAs during Phase I than afterwards (0.0178€, p-value 0.0003), and (d) the lower ASC towards the end of Phase II (0.0011€, p-value 0.0040) than at early stages of Phase II.

Finally, we also include in Table VII the ASC expressed in relative terms to the average future price during each quarter. The median relative ASC for Phase I EUA futures were 0.24% before the market collapse and 0.74% during 2007; for Phase II EUA futures, the median relative ASC dropped from 0.11% in Phase I to about 0.05% during 2008 and 0.03% afterwards. The maximum relative ASC during Phase II were achieved, again, during the first quarter of 2009, 0.07%, far below the minimum relative ASC of Phase I: 0.16% (1^{st} quarter of 2006). Statistical tests in Panel C of Table VII verify the negatively sloped trend for the relative ASC for Phase II EUA futures during both Phase I and II, and the higher relative costs for Phase I EUAs than for Phase II EUAs.

Now, we turn to the volatility decomposition. In Figure 4(a), we plot the estimated price return volatility for Phase I and Phase II EUA futures according to Roll

(1984) with ASC. Volatility showed a decreasing pattern during both phases, with abnormally high levels at the begging of each one, and with only one remarkable outlier at the second quarter of 2006. In Figure 4(b), we plot the estimated friction-related components of volatility: the noisy or transitory component $0.5S^2(1-\alpha)$, and the trade-related efficient component $0.25S^2\alpha^2$, due to information asymmetries. Excluding the above-mentioned outlier, both components showed negative slopes. Statistical tests like those in Panel C of Table VII (not reported) reveal that friction-related volatility was statistically higher for Phase I EUA futures than for Phase II EUA futures; also for Phase II EUA futures during Phase I than during Phase II, and slightly higher during 2008 than during the rest of Phase II. [26] Figure 4(b) also shows that information-related frictions caused systematically less volatility than real frictions.

In Figure 5, we show the quarterly time series of the components of the return volatility as a proportion of the total volatility, according to Roll (1984) with ASC. Grey (black) curves represent Phase I (II) EUA futures. The contribution of the efficient volatility (σ_m^2) decreased to a global minimum of 50.32% at the end of Phase I, during the market collapse, suggesting a lot of noise is price changes during that period. In fact, transitory volatility achieved its maximum level of contribution during the market collapse. The previously reported low average prices and high relative spreads during 2007 suggest that the peak in transitory volatility was largely caused by the bid-ask bounce effect. Meanwhile, trade-related efficient volatility fell from median levels about 6% of total volatility before the market collapse to less than 1% during the market collapse, consistent with the decrease in information asymmetries previously shown.

[26] These tests are available upon request from the authors.

For Phase II EUA futures, the contribution of efficient (transitory) volatility during Phase II was 16.7% lower (higher), in median terms, than for Phase I EUA futures (p-value 0.0001). During Phase II, information-related frictions caused, in median terms, 2.11% of price returns volatility while real frictions accounted for a much remarkable 36.5%. Friction-related volatility showed a steady decrease since the second quarter of 2008. Thus, information-related frictions caused 3.97% of the volatility the first quarter of 2008 vs. 2.05% the last quarter of 2010 (p-value 0.0040), whereas real frictions caused 40.73% of the volatility the first quarter of 2008 and about 28.4% the last quarter of 2010 (p-value, 0.0161).

Finally, Figure 5 shows that the most important contributors to the efficient price volatility were the trade-unrelated innovations. Thus, about 95.6% of the volatility of the efficient price for Phase I EUA futures and 97% for Phase II EUA futures (during Phase II) were friction-free. Moreover, as ASC decreased, the relative importance of the friction-related efficient volatility for Phase II EUA futures decreased, from 6% in Phase I to 3% in Phase II (p-value 0.0038). Market quality (Q^A), that is, $\sigma_u^2 / Var(\Delta p_t)$, sharply deteriorated during the 2007 market breakdown, independently of the underlying asset, but most notably for Phase I EUA futures. For Phase II EUA futures, Q^A increased from 55.3% during the first quarter of 2008 to 70% during the last quarter of 2010 (p-value 0.0080). Despite this improvement in price quality, ECX in 2010 showed quality levels only close to those observed during the early stages of Phase I, before the market collapse, about 73.43% in median terms. The median difference in quality between Phase I before 2007 and Phase II is about 11.8% (p-value 0.0001).

Next, we consider Madhavan, Richardson and Roomans (1997) (hereafter MRR) structural model. We therefore deviate from our prior framework in two ways: First, we allow for serial correlation in the trading process ($\pi \neq 1/2$). Second, we isolate the unpredictable component of the trading process (w_t) and we assume that any information content in the trading process must be contained in it. Table VIII provides the estimated MRR parameters by GMM for each quarter. All the parameters are statistically significant at least at the 5% level; so, we save any reference to significance levels in the Table. The ASC costs (θ) show similar levels and the same decreasing pattern than with the Roll model with ASC previously discussed (see Figure 3). Market making costs (ϕ) are quite stable across time and across phases. The median ϕ for Phase I EUA futures is 0.28% and for Phase II EUA futures during Phase II is 0.20%. Statistical tests fail to reject the null of equal medians between any two sub-periods. Finally, our estimates are consistent with our assumption of serial correlation in the trading process. The probability of trade sign reversal π is always less than 0.5 and higher for Phase I EUA futures than for Phase II EUA futures. Accordingly, the first order autocorrelation of the trading process (ρ) is always positive, moving between 0.4 and 0.6.

In Figure 6, we plot the estimated bid-ask spread and expected realized spread $E(S^r)$ according to the MRR model. The bid-ask spread estimate is very close to that obtained using Roll (1984) with ASC (see Table VII). The realized spread showed a downward trend. During Phase I, the realized spread was 0.113€ the third quarter of 2005 or 0.5% of the average price; at the end of that phase, it was negative (-0.0025€) or -3.6% over the average price. Therefore, the expected profit of market makers per lot round-trip was negative during the collapse of the market. For Phase II EUA futures during Phase I, $E(S^r)$ experienced a -85.5% decrease, from a maximum of 0.0872€ at the end of 2006 (0.43% in relative terms) to 0.0126€ (0.06% in relative terms). The downtrend continued throughout Phase II: the median difference in $E(S^r)$ between

Phase I EUA futures before the collapse and Phase II EUA futures during Phase II was 0.0407€ (p-value 0.0001) per lot round-trip, or 0.21% (p-value 0.0001) over the average price; the median difference in $E(S^r)$ between Phase II EUA futures during Phase I and Phase II was 0.0243€ (p-value 0.0094) per lot round-trip, or 0.11% (p-value 0.0003) in relative terms. Therefore, even though ASC decreased during both in Phase I and II, the expected market making profits per lot round-trip also decreased through time with the decline in bid-ask spreads. Our findings suggest that market makers translated their lower information-asymmetry risk, their operative costs advantages exploiting economies of scale, and their decreased inventory holding costs due the increased trading intensity, to lower bid-ask spreads and, therefore, lower expected market making profits per lot transacted.

In Figure 7, we show the estimated friction-related volatility and its components based on the MRR model. Transitory volatility is the sum of the real frictions component and the price discreteness component, that is, $2\sigma_{\xi}^{2}+2\left(1-\rho\right)\phi^{2}$. Trade-related efficient volatility is due to ASC, that is, $\left(1-\rho^{2}\right)\theta^{2}$.[27] As in the Roll's model with ASC, Figure 7 reveals downward sloping trends in friction-related volatility during both phases. In median terms, friction-related volatility was 0.1453% (p-value 0.0094) greater for Phase I EUA futures during Phase I than for Phase II EUA futures during Phase II. If we exclude the 2007 market collapse, that difference increases to 0.2653% (p-value 0.0001). Informational and real frictions were also larger during the Phase I in median terms, 0.1382% (p-value 0.0001) and 0.0581% (p-value 0.0414), respectively. For Phase II EUA futures, its highest friction-related volatility levels were achieved during the 2007 market collapse (median 0.1168%). Once Phase II started, friction-related volatility dropped to a median 0.0189% (0.0453% in 2008 and 0.0098

[27] The friction-related volatility includes also the interactive term. Its contribution, however, is negligible.

afterwards). For Phase II EUA futures, real and information-related frictions were equally relevant in absolute terms.[28] Finally, Figure 7 shows that the two abnormal periods previously highlighted, second quarter of 2006 and first quarter of 2009, were of a very different nature. During the former, related to the increasing suspicion of over-allocation of EUAs, friction-related volatility was dominated by information-related frictions, i.e. information asymmetries; during the later, linked to the effects of the financial crisis, an abrupt but temporary increase in real frictions accounted for most of the friction-related volatility.

In Figure 8, we plot the quarterly time series of the estimated theoretical volatility components as a proportion of the total estimated volatility of price returns. As in prior figures, grey (black) lines represent Phase I (II) EUA futures. Solid lines represent the quote quality measure in the MRR model (Q^{MRR}). Consistent with Roll's model results, trade-unrelated efficient volatility (σ_u^2) is found again to be the most important component of the efficient volatility (85% during Phase I and 81% during Phase II). The MRR model, however, reports a lower weight for efficient volatility over $Var\left(\Delta p_t\right)$ during the market collapse for Phase I EUA futures, with a minimum of 30.5% at the end of Phase I. Phase II EUA futures efficient volatility contribution also decreased during the market collapse to a minimum of 75.08%. Accordingly, Q^{MRR} shows a global minimum at the end of Phase I (28.91%). Its median before the market collapse was about 68.9%. As a consequence, friction-related variance achieved its global maximum, 63%, at the end of 2007, 61.4% of which was transitory in nature and only 1.57% was information-driven.

[28] In general, by considering the unexpected component of the trading process, the role attributed to information frictions has increased with respect to Roll's (1984) model with ASC.

Comparing Phase I for Phase I EUAs before the 2007 market collapse with Phase II for Phase II EUAs, we find that, in median terms, the role played by frictions in total volatility increased about 14% (p-value 0.0134), 18% if we look only to real frictions (p-value 0.0104). As a result, Q^{MRR} decreased by a remarkable 20.61% (p-value 0.0047). We find no statistical variation in the contribution of the information-related frictions during Phase II with respect to Phase I, meaning that the median decrease in the price quality level is entirely explained by real frictions. Comparing Phase I period for Phase II EUAs, with the commitment period, we get to the same conclusion: the contribution of the transitory volatility increased by 11.66% (p-value 0.0061), efficient volatility weight decreased by 16.48% (p-value 0.0012), and no difference is reported for the contribution of informational frictions. As a result, Q^{MRR} decreased 11.89% (p-value 0.0194). Figure 8 shows an inflection point after the first quarter of 2009, where the contribution of real frictions achieved its maximum of Phase II (56.52%). Afterwards, price quality progressively increased as the influence of transitory volatility progressively decreased. By the end of 2010, transitory volatility represented only 22.76% of $Var\left(\Delta p_t\right)$ and Q^{MRR} was about 63.6%, levels that are just similar to those observed in ECX before the market collapse.

As a last methodological approach, we apply the reduced-form approach of Hasbrouck (1993). In Figure 9, we plot the estimated standard deviation of the pricing error (σ_s) estimated using the VMA representation of the VAR model over the variable set $\left\{r_t, x_t, x_t^s, x_t^{s1/2}\right\}$, with the VAR model truncated at 3 lags. To account for changes in price return volatility through quarters, we express σ_s in relative terms to σ_p. Notice that the ratio σ_s / σ_p plotted in Figure 9 is an inverse measure for market quality.

The findings in Figure 9 are consistent with prior methodologies. According to Hasbrouck (1993) approach, the ECX futures market for EUAs achieved its worst quality levels during the 2007 market collapse. The median σ_s/σ_p before the market collapse was 17.44%, increasing to 53.45% the last quarter of 2007. For Phase II EUA futures, the worst quality levels achieved during Phase II are found the first quarter of 2009 (31.92%). The difference between the median quality during Phase I (excluding 2007) and Phase II is -6.17% (p-value 0.0414). During the most recent quarters, σ_s/σ_p has decreased towards 21.7% the last quarter of 2010. The average decrease with respect to 2008 levels is -2.8% (p-value 0.0161). As in previous methodologies, the market quality levels at the end of 2010 are close but not better than those achieved by ECX during the Phase I before the collapse. In fact, with this methodology, Phase II EUA futures during Phase I showed higher quality levels than during Phase II (-9.19%, p-value 0.0061).

6. Summary and conclusions

We have studied the history of trading frictions and market quality of the European carbon futures market. Two overlapping major events, the market collapse at the end of Phase I, in 2007, and the irruption of the current international financial crisis during Phase II, have characterized the short history of this pan-European platform.

We have used a unique database provided by ICE ECX futures market, the most active trading platform of the EU-ETS. The database offers detailed information on all ECX trades on EUA future contracts, covering maturities both on Phase I and II. We have applied three different microstructure approaches to obtain estimates of trading frictions and market quality: a structural model of price formation with and without information asymmetries based on Roll (1984) stylized framework; the alternative structural model proposed by Madhavan, Richardson and Roomans (1997), and the reduced-form approach proposed by Hasbrouck (1993).

In terms of trading frictions, the two structural model approaches previously mentioned lead to similar conclusions. According to Roll (1984) model with adverse selection costs (ASC), the estimated bid-ask spread and relative spreads were higher in median terms during Phase I (0.0675€) than during Phase II (0.0186€). Although we evidence a downtrend in bid-ask spreads during both phases, relative spreads were abnormally high during the 2007 market collapse, when EUA prices fell below 1€, achieving a maximum of 13.68% of the EUA future price at the end of Phase I.

Regarding adverse selection costs (ASC), they represented 65% of the bid-ask spread (0.088€) at the start of Phase I, but only 17.5% (0.0017€) by the end of 2007. During Phase II, ASC were about 30% of the spread (0.0053€). In median terms, the difference in ASC between Phase I and Phase II was about 18% of the spread (or 0.0353€). In relative terms, the median ASC dropped from 0.11% of the EUA futures price during Phase I to 0.03% towards the end of Phase II. The maximum relative ASC was achieved during the market collapse (0.74% during 2007).

According to the MRR model, even though ASC, in absolute terms, decreased during both in Phase I and II, the expected market making profits per lot round-trip, as measured by the expected realized spread, also decreased through time with the decline in bid-ask spreads. We suggest that market makers translated their lower market making costs (i.e., ASC, inventory holding costs, order processing costs) to their quoted bid-ask spreads and, therefore, lower expected market making profits per lot transacted.

Price return volatility decreased during both phases and also its friction-related components, either information-related (due to ASC) or information-unrelated (due to real frictions). In absolute terms, friction-related volatility and its components were higher during Phase I than during Phase II. Both methods also coincide in the fact that real-frictions caused systematically more volatility than informational frictions. In relative terms, however, the picture we report is different. The two structural models considered attribute an increasingly less important relative role to efficient price volatility along Phase I and, consequently, an increasing relative role to friction-related volatility. According to the MRR model, efficient volatility accounted for only 30.5% of the price return volatility during the 2007 market breakdown. However, when Phase I before the collapse is compared with Phase II, the median contribution of friction-related volatility to price return volatility was 14% higher (18% if we look only to real frictions) during Phase II, with a maximum contribution of 56.52% the first quarter of 2009. After that quarter, the weight of friction-related volatility has progressively decreased.

Summary measures of market quality proposed by the three methodological approaches generate the same conclusions. ECX achieved its lowest levels of quality during the 2007 market breakdown. With Roll (1984) with ASC, 49.4% of the price return volatility was not friction-related by the end of Phase I; with MRR model, this contribution decreases to 28.91%, and with Hasbrouck (1993), the standard deviation of the pricing error increases to a maximum of 53.54% of the price return variance. All models coincide in that market quality progressively recovered during Phase II. Roll (1984) with ASC shows a steady recovery, which started from the very beginning of Phase II, whereas MRR and Hasbrouck (1993) show a late recovery, which started the second quarter of 2009. In all cases, however, the market quality levels observed by the end of our sample period (2010) are close but not superior to those observed during Phase I before the market collapsed.

Our analysis identifies one intermediate unusual period in each Phase, the second quarter of 2006, when the initial suspicions about over-allocation of EUAs raised, and the first quarter of 2009, a period market by the definitive outbreak of the current financial crisis after the collapse of Lehmann Brothers on September 15th, 2008, and all the events that followed, including the worst two-month period (January and February 2009) in the history of S&P500, with a 18.62% drop and the Dow Jones Industrial Average Index showing historical minimums since 1996, and the Euro Stoxx 50 at minimums not achieved since 2003. During the second quarter of 2006, ECX showed abrupt peaks in bid-ask spreads, relative spreads, adverse selection costs, and price return volatility. MRR model results however, suggest that most of the volatility increase was information-related, rather than transitory, so that market quality does not deteriorated. During the first quarter of 2009, there were also peaks in price return volatility, but MRR and Hasbrouck (1993) methodologies both indicate that, in this case, transitory volatility dominated, so that market quality decreased.

Given the previous evidence, we must conclude that the quality of the ECX market has not remarkably changed from futures contracts with maturities in Phase I to those in Phase II. Even though Phase II shows higher trading intensity, lower immediacy costs (as measured by the bid-ask spread), lower risk of information asymmetries or adverse selection costs, and lower both price return volatility and friction-related volatility than Phase I (before the market collapse), friction-related volatility contribution to total volatility has been above ordinary Phase I levels. Our findings suggest that market quality has been recovering from the market breakdown at the end of Phase I and the additional negative impact of the international financial crisis on the real economy expectations. By the end of 2010, this recovery process has not finished yet.

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Table I. Market shares

This table reports yearly market shares of the two most representative market platforms of the EU-ETS, BlueNext and ECX, in the spot (Panel A) and futures (Panel B) markets for EUAs. Volume is measured in lots. Each lot represents 1,000 tonnes of CO_2 equivalent.

Panel A: Spot Market

	Phase I*	Shares		Phase II	Shares		
Year	Total (lots)	BlueNext	Others	Total (lots)	BlueNext	ECX	Others
2005	7,110,791	61.34%	38.66%				
2006	40,222,846	78.18%	21.82%				
2007	29,647,143	83.11%	16.89%				
2008	3,389,504	80.72%	19.28%	244,480,000	100%	0%	0.00%
2009				1,246,871,011	90.07%	4.85%	5.08%
2010				493,347,359	54.70%	39.48%	5.82%

Panel B: Futures market

	Phase I	Shares		Phase II	Shares		
Year	Total (lots)	ECX	Others	Total (lots)	BlueNext	ECX	Others
2005	89,409,000	100%	0.00%	3,554,000		100.00%	0.00%
2006	315,280,000	100%	0.00%	128,306,505		99.66%	0.34%
2007	110,089,000	100%	0.00%	872,876,000		99.18%	0.82%
2008				2,017,544,000	0.08%	98.57%	1.35%
2009				3,803,708,650	0.01%	98.95%	1.04%
2010				4,429,652,000	0.00%	96.40%	3.60%

* NASDAQ OMX Commodities Europe data not available.

Source : CDC Climat, using data from BlueNext, ICE ECX, GreenX and Reuters.

Table II. Trading activity per future contract

This table provides statistics on trading activity for the different ECX EUA future contracts, both in Phase I and Phase II.

Phase	Delivery	Number of trades	Average price	Volume (lots)	Average trade size (lots)	First trade: Day	First trade: Time	Last trade: Day	Last trade: Time
1	Dec-05	4,784	22.47	51,812	10.83	4/22/2005	7:00 AM	12/19/2005	12:35 PM
1	Mar-06	476	24.76	7,7	16.18	10/11/2005	4:10 PM	3/24/2006	4:57 PM
1	Jun-06	43	22.47	879	20.44	1/9/2006	12:02 PM	6/23/2006	7:08 AM
1	Sep-06	10	16.33	220	22	7/18/2006	1:45 PM	9/19/2006	12:46 PM
1	Oct-06	8	12.63	80	10	10/13/2006	12:23 PM	10/19/2006	8:15 AM
1	Nov-06	4	15.01	80	20	7/25/2006	3:37 PM	10/30/2006	9:43 AM
1	Dec-06	20,855	18.12	248,6	11.92	4/28/2005	9:30 AM	12/18/2006	4:19 PM
1	Jan-07	3	18.88	30	10	12/29/2006	10:37 AM	1/9/2007	4:51 PM
1	Feb-07	1	1.6	25	25	2/9/2007	5:15 PM	2/9/2007	5:15 PM
1	Mar-07	70	4.39	8,638	123.4	1/19/2006	12:22 PM	3/26/2007	4:27 PM
1	Jun-07	1	0.19	200	200	6/13/2007	11:29 AM	6/13/2007	11:29 AM
1	Dec-07	13,541	8.5	213,636	15.78	4/26/2005	10:30 AM	12/17/2007	4:13 PM
2	Jan-08	14	20.62	300	21.43	3/15/2007	6:05 PM	1/24/2008	5:21 PM
2	Feb-08	24	90.18	24	1	1/18/2008	6:10 PM	1/21/2008	12:19 PM
1	Mar-08	42	1.96	1,838	43.76	2/2/2006	1:44 PM	3/31/2008	3:59 PM
2	Dec-08	238,647	21.93	2,188,980	9.17	6/17/2005	4:04 PM	12/15/2008	4:41 PM
2	Mar-09	170	11.47	11,905	70.03	12/1/2008	11:15 AM	3/30/2009	3:17 PM
2	Jun-09	4	17.95	105	26.25	11/6/2008	3:47 PM	4/24/2009	3:46 PM
2	Sep-09	28	14.11	796	28.43	5/27/2009	2:19 PM	9/25/2009	4:26 PM
2	Dec-09	312,130	13.85	3,057,609	9.8	10/12/2005	1:20 PM	12/14/2009	5:17 PM
2	Mar-10	32	13.81	1,804	56.38	9/4/2009	2:46 PM	3/19/2010	11:46 AM
2	Jun-10	8	14.85	335	41.88	2/17/2010	5:03 PM	6/28/2010	3:23 PM
2	Sep-10	14	15.07	390	27.86	4/15/2010	4:32 PM	9/24/2010	9:32 AM
2	Dec-10	289,726	14.57	3,078,319	10.62	1/26/2006	5:05 PM	9/27/2010	4:48 PM
2	Mar-11	9	15.17	454	50.44	3/10/2010	12:35 PM	6/15/2010	4:07 PM
2	Jun-11	3	15.67	75	25	5/6/2010	2:37 PM	5/11/2010	1:50 PM
2	Sep-11	3	15.78	75	25	5/6/2010	2:37 PM	5/11/2010	1:51 PM
2	Dec-11	49,427	15.46	652,982	13.21	3/23/2006	1:39 PM	9/27/2010	4:12 PM
2	Mar-12	5	15.7	137	27.4	4/14/2010	12:34 PM	6/8/2010	11:53 AM
2	Jun-12	3	15.71	75	25	4/14/2010	12:34 PM	5/11/2010	1:48 PM
2	Sep-12	3	15.88	75	25	4/14/2010	12:35 PM	5/11/2010	1:47 PM
2	Dec-12	50,650	16.6	981,907	19.39	3/22/2006	5:21 PM	9/27/2010	4:44 PM

Table III. Sample data: General statistics

This table contains sample descriptive statistics per contract. Panel A provides price statistics and aggregate trading and trade-size statistics. Panel B reports trade-related statistics. One lot equals 1,000 tonnes of CO_2 equivalent. We also include statistics for two continuous time series obtained by rolling over the time series of the finite-life future contracts negotiated in ECX. There is one rollover time series for each phase of the EU-ETS we consider.

Panel A: General statistics

Phase	Delivery	Average price	Price std. deviation	Maximum price	Minimum price	# price changes per day	# trades	Volume (lots)	Average trade size (lots)
1	Dec. 2005	22.47	2.95	29.50	6.50	20.44	4,784	51,812	10.83
1	Dec. 2006	18.12	6.60	31.00	6.30	33.02	20,855	248,600	11.92
1	Dec. 2007	8.50	8.34	32.05	0.01	10.82	13,541	213,636	15.78
2	Dec. 2008	21.93	3.38	33.70	10.75	143.75	238,647	2,188,980	9.17
2	Dec. 2009	13.85	2.77	32.50	7.70	113.93	312,130	3,057,609	9.80
2	Dec. 2010	14.61	1.61	32.22	8.25	92.28	330,390	3,598,073	10.89
2	Dec. 2011	15.35	2.57	32.98	8.60	20.21	64,224	890,617	13.87
2	Dec. 2012	16.46	3.41	34.65	8.23	19.55	58,109	1,141,885	19.65
1	Rollover	14.97	8.95	31.00	0.01	26.52	32,108	406,228	12.65
2	Rollover	16.25	4.26	33.70	7.70	268.43	818,322	7,863,240	9.61

Panel B: Trading statistics

Phase	Delivery	First trading day	First trade	Last trading day (in sample)	Last trade	# trading days	# trades per day	# trades per minute	Average trade duration in minutes (excl. overnight)
1	Dec. 2005	4/22/05	4/22/05 7:00 AM	12/19/05	12/19/05 12:35 PM	169	28.31	0.0489	20.43
1	Dec. 2006	4/22/05	4/28/05 9:30 AM	12/18/06	12/18/06 4:19 PM	423	49.30	0.0858	11.65
1	Dec. 2007	4/22/05	4/26/05 10:30 AM	12/17/07	12/17/07 4:13 PM	679	19.94	0.0341	29.28
2	Dec. 2008	4/22/05	6/17/05 4:04 PM	12/15/08	12/15/08 4:41 PM	934	255.51	0.4347	2.30
2	Dec. 2009	4/22/05	10/12/05 1:20 PM	12/14/09	12/14/09 5:17 PM	1,188	262.74	0.4454	2.25
2	Dec. 2010	4/22/05	1/26/06 5:05 PM	12/20/10	12/20/10 4:59 PM	1,447	228.33	0.3862	2.59
2	Dec. 2011	4/22/05	3/23/06 1:39 PM	12/31/10	12/31/10 11:59 AM	1,454	44.17	0.0748	13.38
2	Dec. 2012	4/22/05	3/22/06 5:21 PM	12/31/10	12/31/10 11:59 AM	1,454	39.96	0.0676	14.78
1	Rollover	4/22/05	4/22/05 7:00 AM	3/31/08	3/31/08 3:59 PM	750	42.81	0.0732	13.66
2	Rollover	4/22/05	6/17/05 4:04 PM	12/31/10	12/31/10 11:59 AM	1,454	562.81	0.9525	1.05

Table IV. Rollover

This Table reports the rollover dates resulting from applying the maximum volume criterion to obtain two time series, one for each phase of the EU-ETS, from the time series of the finite-life future contracts negotiated in ECX.

Futures Phase I		
Maturity	First day	Last day
Dec-05	4/22/2005	11/18/2005
Dec-06	11/21/2005	11/21/2006
Dec-07	11/22/2006	12/17/2007
Futures Phase II		
Maturity	First day	Last day
Dec-08	4/22/2005	12/8/2008
Dec-09	12/9/2008	12/3/2009
Dec-10	12/4/2009	12/16/2010
Dec-11	12/17/2010	12/31/2010

Table V. Trade types

This table contains statistics on the different types of trades available in the ECX database we use in our study. We provide the number of trades (Panel A) and the total volume (Panel B) in each type of trade for the ECX EUA future contracts of Phase I and Phase II of the EU-ETS.

Panel A: Number of trades

	Future Phase I		Future Phase II	
EXC trade type	# trades	%	# trades	%
Screen trade (regular, on-exchange)	20,260	63.10	683,584	83.53
Screen cross trade (same Clearing Member)	771	2.40	26,448	3.23
On-screen corrections	66	0.21	514	0.06
Block trade	2	0.01	168	0.02
EFP/EFS trade	11,009	34.29	107,601	13.15
Bilateral off-exchange	0	0.00	2	0.00
Settlement trade	0	0.00	5	0.00
Total	32,108	100	818,322	100

Panel B: Volume

	Future Phase I		Future Phase II	
EXC trade type	Volume	%	Volume	%
Screen trade (regular, on-exchange)	180,934	44.54	4,076,857	51.85
Screen cross trade (same Clearing Member)	7,959	1.96	183,756	2.34
On-screen corrections	1,459	0.36	10,981	0.14
Block trade	500	0.12	21,714	0.28
EFP/EFS trade	215,376	53.02	3,569,836	45.40
Bilateral off-exchange	0	0.00	36	0.00
Settlement trade	0	0.00	60	0.00
Total	406,228	100	7,863,240	100

Table VI. Trading activity per quarter

We provide trading statistics per quarter in our sample period. We distinguish between Phase I trading activity and Phase II trading activity. For each phase of the EU-ETS we report the number of trades, the traded volume (in shares), the net number of trades (buys minus sells) and the net volume (buy volume minus sell volume).

		Phase I trading activity				Phase II trading activity			
Quarter		Trades	Volume	Net trades	Net volume	Trades	Volume	Net trades	Net volume
3	2,005	2,063	15,324	241	1,580				
4	2,005	1,127	9,545	55	721				
1	2,006	2,672	27,057	-64	-1,499				
2	2,006	3,966	35,990	-180	-2,042				
3	2,006	2,116	17,867	-66	-1,171				
4	2,006	3,499	23,186	-125	-310	3,349	30,610	-133	-1,320
1	2,007	3,057	22,594	-509	-3,098	5,014	43,965	148	2,263
2	2,007	1,259	15,431	-125	-2,923	10,655	70,891	973	6,547
3	2,007	501	13,940	3	40	13,542	97,693	812	4,669
4	2,007					11,531	70,679	923	7,097
1	2,008					27,826	128,874	1,604	15,618
2	2,008					31,095	144,194	3,523	20,396
3	2,008					43,550	200,428	1,394	3,982
4	2,008					38,687	162,838	-1,867	-8,658
1	2,009					60,357	290,421	-1,535	-14,401
2	2,009					85,770	338,841	4,962	-2,553
3	2,009					59,823	278,654	-1,273	-18,214
4	2,009					39,992	271,628	-2,084	-12,638
1	2,010					53,540	390,655	-1,148	-12,069
2	2,010					105,584	727,938	4,566	25,926
3	2,010					54,476	436,825	292	15,223
4	2,010					38,793	391,723	645	8,973

Table VII. Bid-ask spread and adverse selection costs: Roll (1984) model

This table reports the estimates of the Roll (1984) estimate of the bid-ask spread and the relative bid-ask spread (*S*) for each quarter in our sample. We also estimate a version of Roll's model with adverse selection costs. We report the adverse selection costs parameter (α), the bid-ask spread (*S*), the adverse selection costs (αS), and the relative adverse selection costs ($\alpha S/P$), where *P* is the average price. Panel A reports the findings for Phase I EUAs future contracts and Panel B reports the findings for Phase II EUAs future contracts. All the reported coefficients in Panels A and B are statistically significant at usual levels. Panel C contains estimates of the average trend of each statistic for the Phase II EUAs future contracts, both including and excluding Phase I data. Panel C also includes non-parametric Mann-Whitney U-Tests for differences in medians between different sub-periods.

Panel A: Phase I EUAs							
Roll (1984) original model				Roll (1984) with adverse-selection costs			
Quarter	Year	S	Relat. S	α	S	αS	(αS/P)%
3	2005	0.0910	0.0040	0.6519	0.1350	0.0880	0.3895
4	2005	0.0702	0.0032	0.4837	0.0928	0.0449	0.2031
1	2006	0.0599	0.0023	0.5251	0.0812	0.0426	0.1595
2	2006	0.1100	0.0070	0.5628	0.1531	0.0862	0.5337
3	2006	0.0472	0.0030	0.6010	0.0675	0.0406	0.2488
4	2006	0.0401	0.0045	0.4224	0.0509	0.0215	0.2349
1	2007	0.0264	0.0148	0.4100	0.0332	0.0136	0.6478
2	2007	0.0179	0.0391	0.2037	0.0200	0.0041	0.7400
3	2007	0.0091	0.1368	0.1749	0.0100	0.0017	2.4965
Panel B: Phase II EUAs							
4	2006	0.0826	0.0045	0.5053	0.1105	0.0558	0.2725
1	2007	0.0558	0.0038	0.4406	0.0715	0.0315	0.2074
2	2007	0.0405	0.0020	0.4431	0.0521	0.0231	0.1056
3	2007	0.0315	0.0016	0.4082	0.0395	0.0161	0.0797
4	2007	0.0272	0.0012	0.3866	0.0337	0.0130	0.0577
1	2008	0.0282	0.0013	0.3547	0.0343	0.0122	0.0571
2	2008	0.0253	0.0010	0.3009	0.0298	0.0090	0.0352
3	2008	0.0294	0.0012	0.3355	0.0353	0.0118	0.0484
4	2008	0.0298	0.0016	0.2947	0.0350	0.0103	0.0568
1	2009	0.0281	0.0025	0.2511	0.0322	0.0081	0.0717
2	2009	0.0194	0.0014	0.2699	0.0225	0.0061	0.0444
3	2009	0.0125	0.0009	0.3061	0.0148	0.0045	0.0317
4	2009	0.0120	0.0009	0.3158	0.0142	0.0045	0.0326
1	2010	0.0122	0.0009	0.2777	0.0142	0.0039	0.0302
2	2010	0.0101	0.0007	0.2817	0.0118	0.0033	0.0217
3	2010	0.0090	0.0006	0.3043	0.0106	0.0032	0.0219
4	2010	0.0082	0.0006	0.3147	0.0098	0.0031	0.0206
Panel C: Tests							
Average trend of Phase II EUAs (%):							
a. Including pre-Phase II data		**-0.2216**	**-0.0075**	**-1.1344**	**-0.2916**	**-0.1013**	**-0.8145**
b. Excluding pre-Phase II data		**-0.2237**	**-0.0072**	-0.2026	**-0.2687**	**-0.0893**	**-0.5416**
Mann-Whitney U-test PI vs. PII EUAs:							
c. PI vs. PII since 2008		**0.0312**	**0.0036**	**0.1811**	**0.0488**	**0.0353**	**0.2412**
d. PI except 2007 vs. PII since 2008		**0.0490**	**0.0027**	**0.2414**	**0.0683**	**0.0385**	**0.1323**
e. PI except 2007 vs. PII only 2008		**0.0362**	**0.0023**	**0.2258**	**0.0523**	**0.0327**	**0.1125**
Mann-Whitney U-test PII EUAs:							
f. Before 2008 vs. after 2008		**0.0246**	**0.0010**	**0.1380**	**0.0334**	**0.0178**	**0.0526**
g. Only 2008 vs. PII after 2008		**0.0039**	0.0001	0.0096	**0.0044**	**0.0011**	0.0089

* Bold format means statistically significant (at least) at the 5% level.

Table VIII. MRR (1997) parameter estimates

This table reports the estimated parameters of Madhavan, Richardson, and Roomans's (1997) structural model of price formation for each quarter in our sample. The model is estimated by GMM. θ is the adverse selection costs parameter; ϕ is the market making costs (real frictions) parameter; ρ is the first order correlation in the trade sign, and π is the probability of a trade sign reversal. Panel A (B) contains the findings for Phase I (II) of the EU-ETS. All the reported coefficients in Panels A and B are statistically significant at usual levels. Panel C includes non-parametric Mann-Whitney U-Tests for differences in medians between different sub-periods.

Panel A: Phase I EUAs

Quarter	Year	θ	ϕ	ρ	π
3	2005	0.0899	-0.0147	0.4459	0.2771
4	2005	0.0406	0.0151	0.3778	0.3111
1	2006	0.0419	0.0028	0.4419	0.2790
2	2006	0.0902	-0.0095	0.4944	0.2528
3	2006	0.0354	0.0016	0.3926	0.3037
4	2006	0.0230	0.0040	0.5144	0.2428
1	2007	0.0149	0.0022	0.5633	0.2183
2	2007	0.0051	0.0054	0.6038	0.1981
3	2007	0.0016	0.0041	0.5000	0.2500

Panel B: Phase II EUAs

Quarter	Year	θ	ϕ	ρ	π
4	2006	0.0722	-0.0072	0.4395	0.2803
1	2007	0.0340	0.0028	0.4996	0.2502
2	2007	0.0295	-0.0024	0.5980	0.2010
3	2007	0.0183	0.0022	0.5353	0.2323
4	2007	0.0165	0.0010	0.5812	0.2094
1	2008	0.0155	0.0020	0.5941	0.2030
2	2008	0.0124	0.0028	0.6280	0.1860
3	2008	0.0149	0.0031	0.5916	0.2042
4	2008	0.0130	0.0049	0.6007	0.1997
1	2009	0.0105	0.0056	0.6056	0.1972
2	2009	0.0078	0.0034	0.6086	0.1957
3	2009	0.0059	0.0015	0.6132	0.1934
4	2009	0.0057	0.0014	0.6042	0.1979
1	2010	0.0052	0.0019	0.6194	0.1903
2	2010	0.0042	0.0017	0.6039	0.1980
3	2010	0.0041	0.0013	0.6019	0.1991
4	2010	0.0038	0.0012	0.5847	0.2076

Panel C: Tests	θ	ϕ	ρ	π
Average trend of Phase II EUAs (x100):				
a. Including pre-Phase II data	**-0.1202**	-0.0079	0.0575	-0.0287
b. Excluding pre-Phase II data	**-0.1162**	-0.0190	-0.0347	0.0173
Mann-Whitney U-test PI vs. PII EUAs:				
c. PI vs. PII since 2008	**0.0286**	0.0008	**-0.1096**	**0.0548**
d. PI except 2007 vs. PII since 2008	**0.0344**	0.0002	**-0.1601**	**0.0801**
e. PI except 2007 vs. PII only 2008	**0.0273**	-0.0008	**-0.1535**	**0.0767**
Mann-Whitney U-test PII EUAs:				
f. Before 2008 vs. after 2008	**0.0227**	-0.0010	**-0.0688**	**0.0344**
g. Only 2008 vs. PII after 2008	**0.0014**	0.0003	-0.0009	0.0004

* Bold format means statistically significant (at least) at the 5% level.

Figure 1. EUA future prices

We plot the time series of future prices for two contracts: EUA December 2007 futures contract and EUA December 2012 futures contract, as the futures prices representative for Phase I and II, respectively.

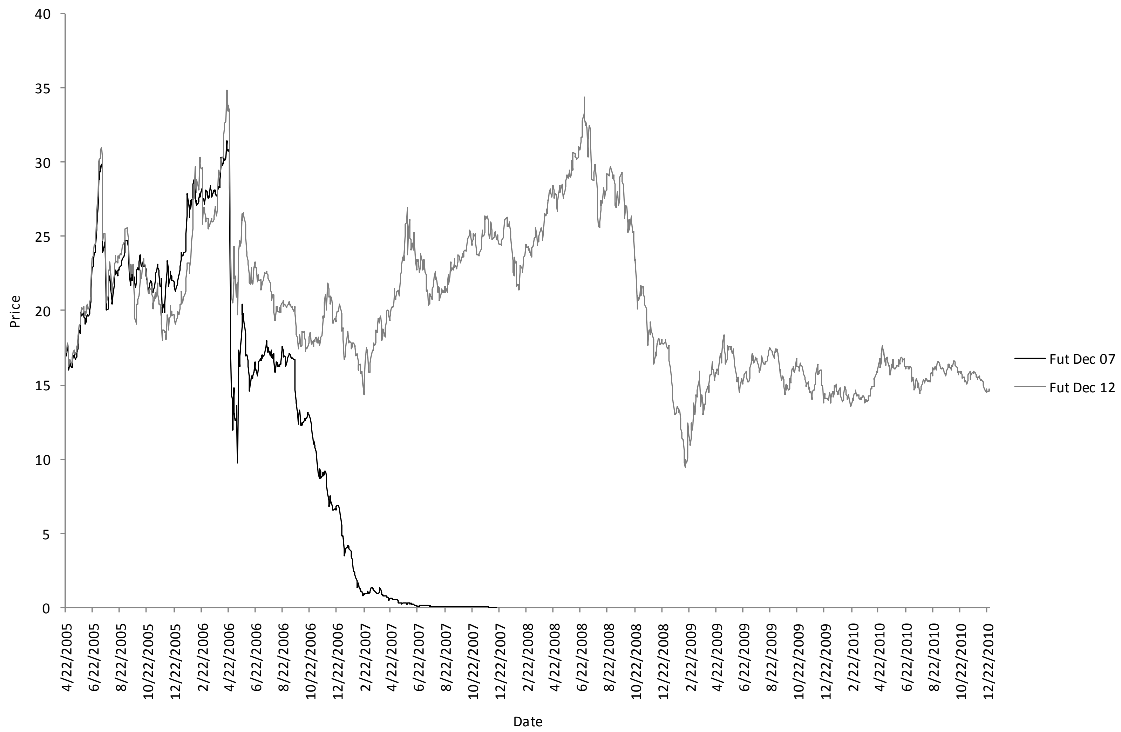


Figure 2. December EUA futures: Accumulated volume

We plot the accumulated volume (in millions of lots) through time of the EUA future contracts with expiry dates from December 2005 to December 2012.

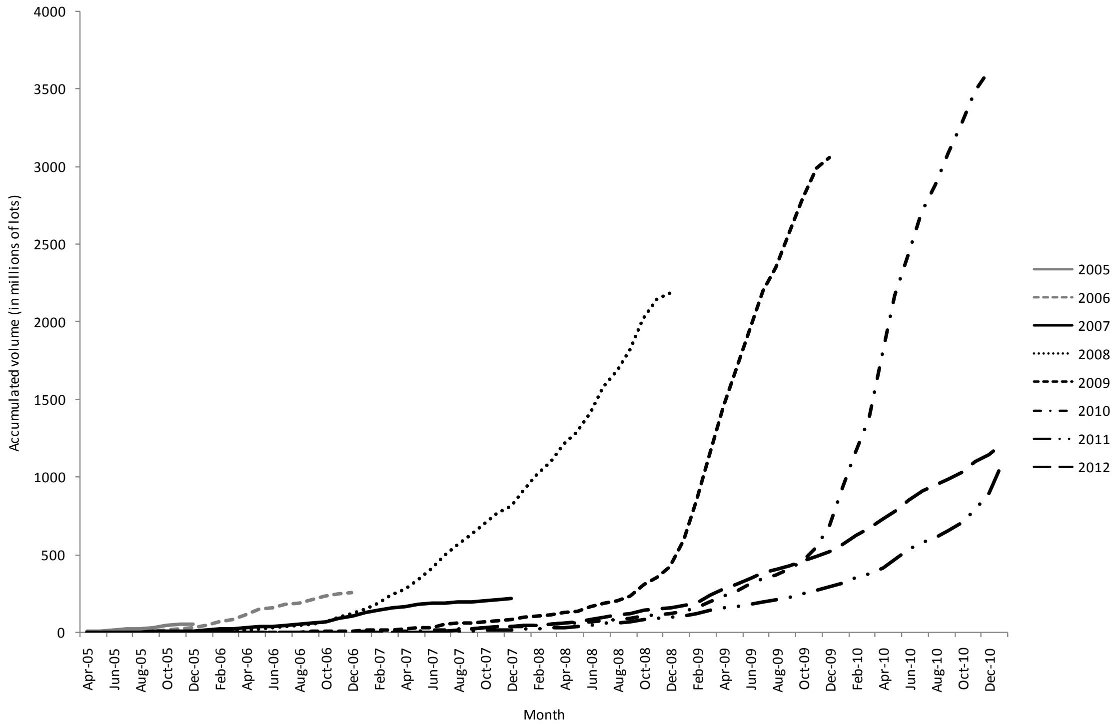


Figure 3. Adverse selection costs (αS): Roll's (1984) model with adverse selection costs

We plot the adverse selection costs evolution through time according to Roll (1984) model extended, to account for information asymmetries.

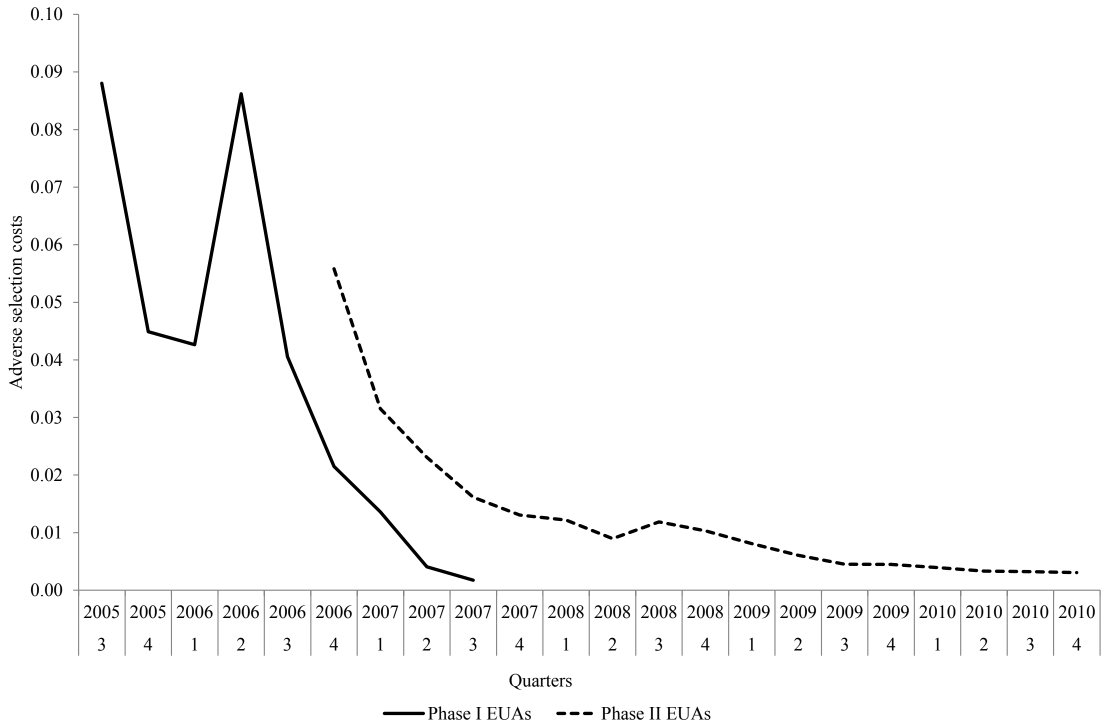
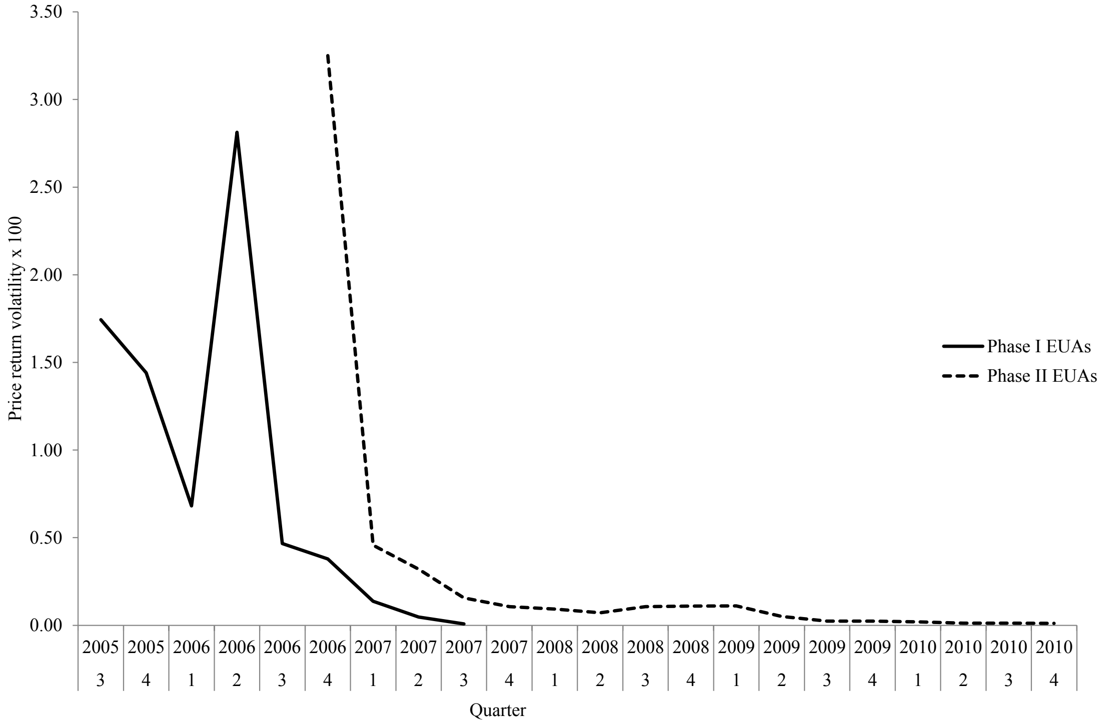
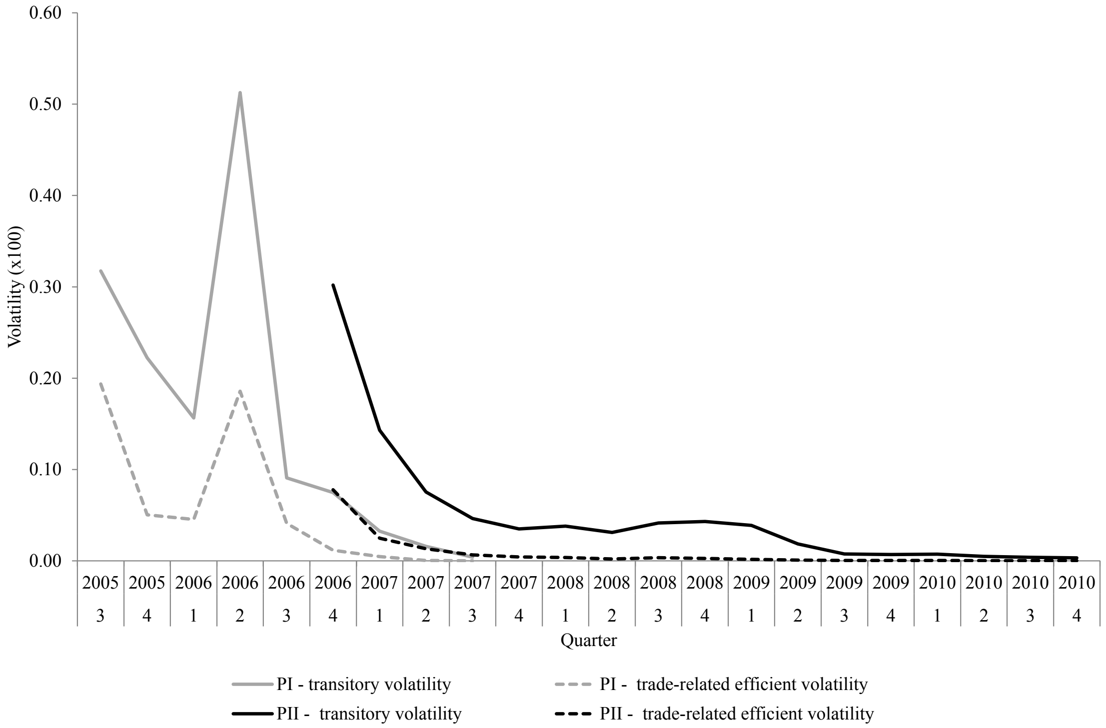


Figure 4. Friction-related volatility: Roll's (1984) model with adverse selection costs

In Figure 4(a), we plot the estimated price return volatility for Phase I and Phase II EUA futures according to Roll (1984) model with adverse selection costs. In Figure 4(b), we plot the estimated friction-related components of volatility: the noisy or transitory component, and the trade-related efficient component, due to information asymmetries.



(a) Price change volatility



(b) Friction-related volatility

Figure 5. Volatility decomposition: Roll's (1984) model with adverse selection costs

Based on the volatility decomposition obtained with the estimates of Roll (1984) model with adverse selection costs, we plot the evolution through time of the portion of price return volatility due to: (a) the efficient price volatility; (b) the trade-related efficient volatility ("trade-related volatility"); (c) the trade-unrelated efficient volatility ("trade-unrelated volatility"), which is our measure of quote quality (Q^A), and (d) the real friction-related (noisy) volatility ("transitory volatility"). We estimate the model for each quarter in our sample, and for each of the first two phases of the EU-ETS.

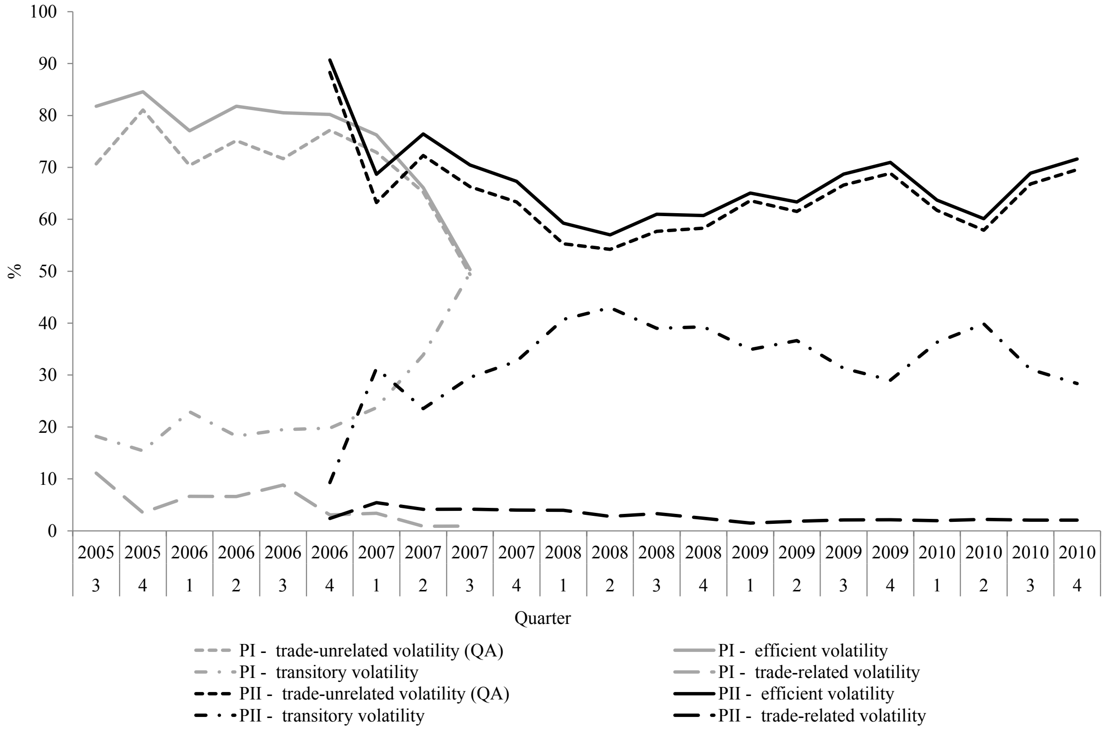


Figure 6. Bid-ask spread and expected realized spread: MRR (1997) approach

Based on the estimated structural model of price formation proposed by Madhavan, Richardson, and Roomans (1997), we plot the estimated bid-ask spread and expected realized spread for each quarter in our sample period and for both Phase I and Phase II of the EU-ETS.

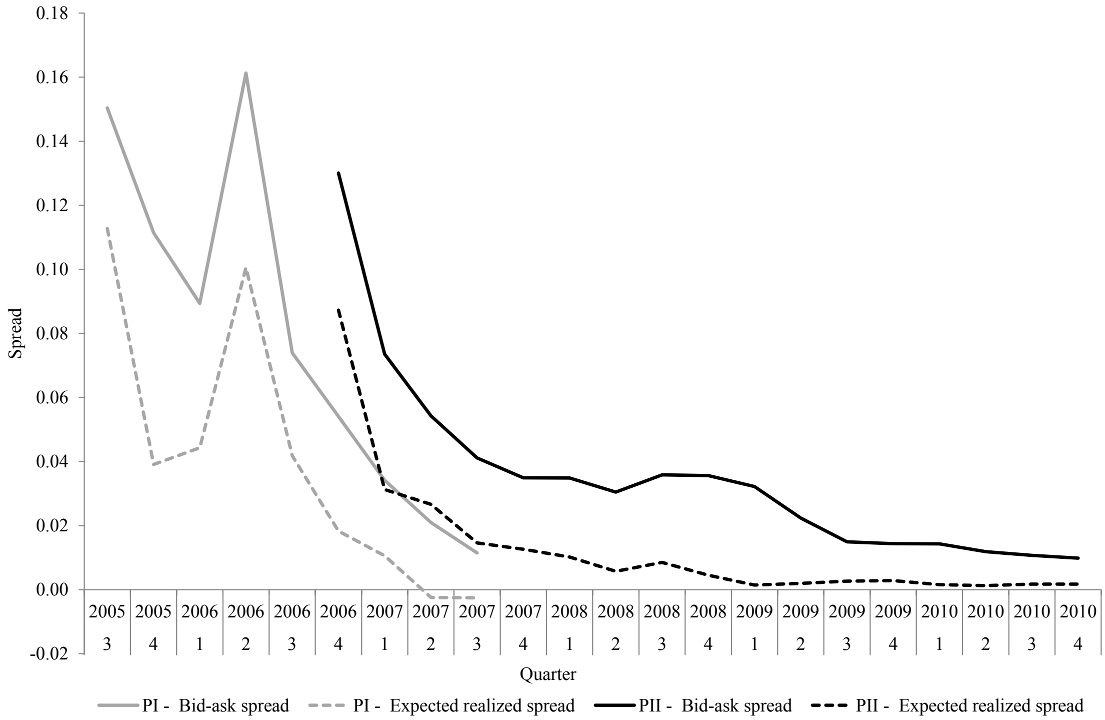


Figure 7. Friction-related volatility decomposition: MRR (1997) approach

Based on the estimated structural model of price formation proposed by Madhavan, Richardson, and Roomans (1997), we plot the estimated friction-related volatility and its components for each quarter in our sample. We distinguish between the trade-related efficient volatility (due to informational frictions), and the transitory volatility (due to real frictions). We estimate the model for each quarter in our sample, and for each of the first two phases of the EU-ETS.

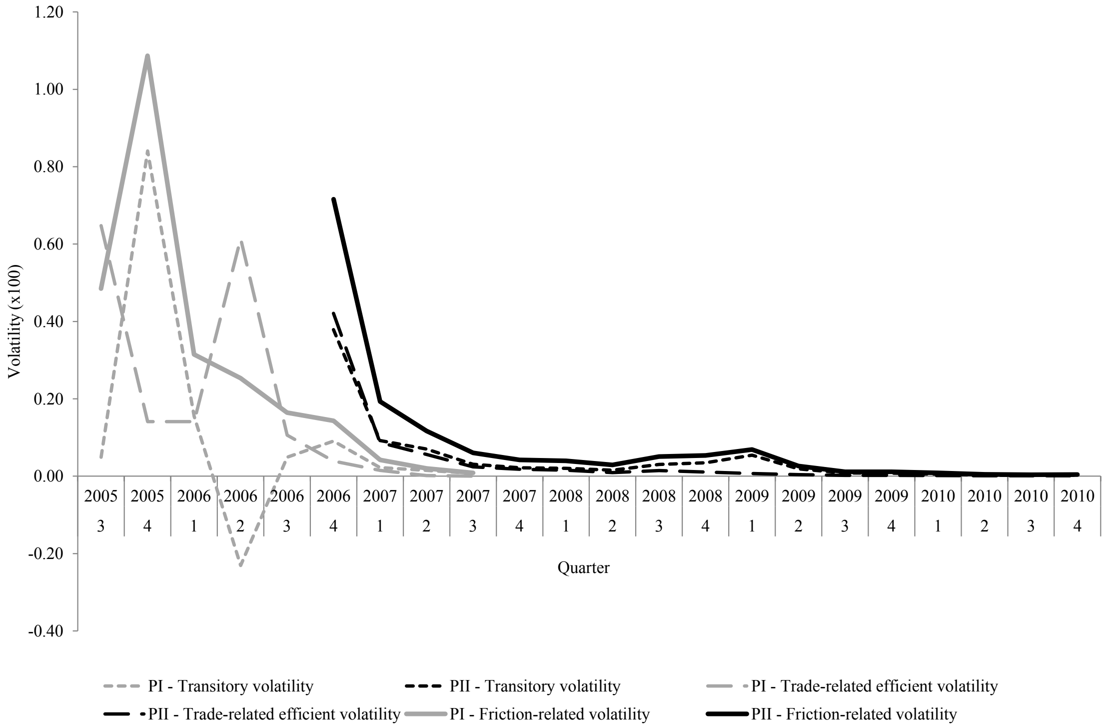


Figure 8. Quality of prices: MRR (1997) approach

Based on the estimated structural model of price formation proposed by Madhavan, Richardson, and Roomans (1997), we plot the evolution through time of the portion of price return volatility due to: (a) the trade-related efficient volatility ("trade-related volatility"); (b) the trade-unrelated efficient volatility ("trade-unrelated volatility"), which is our measure of quote quality (Q^{MRR}), and (c) the real friction-related (noisy) volatility ("transitory volatility"). We estimate the model for each quarter in our sample, and for each of the first two phases of the EU-ETS.

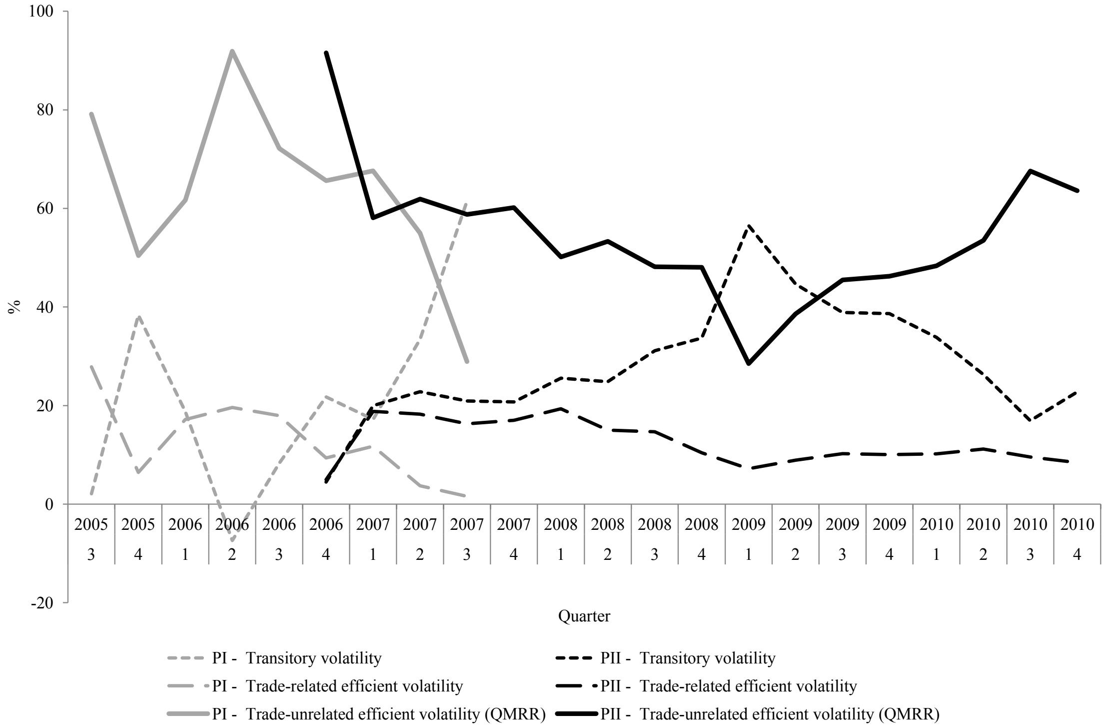
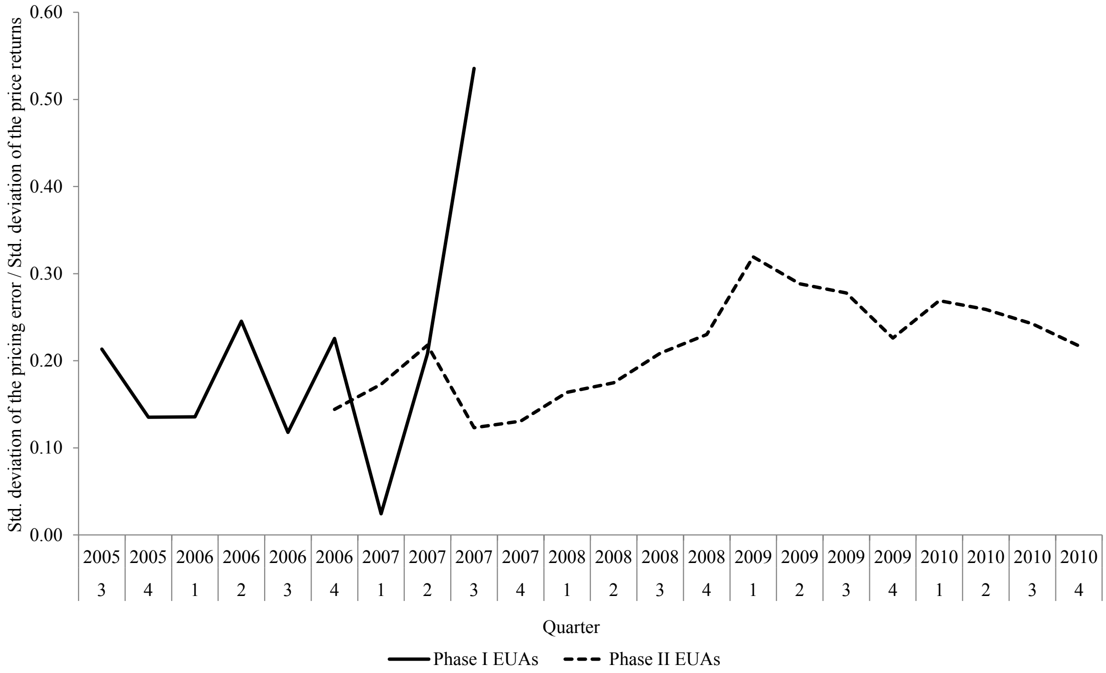


Figure 9. Quality of prices: Hasbrouck (1993) approach

We plot the estimated standard deviation of the pricing error according to reduced-form methodology proposed by Hasbrouck (1993). We use the VMA representation of a VAR model over a variable set which includes the continuously compounded price return, the trade sign, the signed trade size, and the signed square root of the trade size, with the VAR model truncated at 3 lags. The standard deviation of the pricing error is represented in relative terms to the standard deviation of the continuously compounded price return. This metric is an inverse proxy for market quality.



Chapter IV

Modeling the Probability of Informed Trading in the European Carbon Market

1. Introduction

According to data form Kossoy and Ambrosi (2011) (World Bank), carbon offsets were the second most traded "commodity" around the world in 2010. We contribute to the growing line of research that studies the characteristics and particularities of this relatively new market by studying information-motivated trading in the European Union Emissions Trading Scheme (EU-ETS).

Informed trading is analyzed using the very well-known PIN methodology introduced by Easley, Kiefer, O'Hara and Paperman (1996) (hereafter, EKOP).[1] Building on the fundamentals discussed in Easley and O'Hara (1987, 1992), EKOP develop the original PIN model to test whether differences in informed trading intensity could explain the differences observed in spreads between frequently and infrequently traded NYSE-listed stocks. Easley, Kiefer and O'Hara (1996, 1997), and Easley, Hvidkjaer and O'Hara (2002) provide examples of alternative applications of the original PIN methodology. Extension of the original methodology for particular research problems are provided, among others, by Easley, O'Hara and Saar (2001) and Easley, Engle, O'Hara and Wu (2008).[2] In this paper, we adapt the EKOP model to the particularities of the EU-ETS.

Under the EU-ETS, there are two main emission certificates that polluting companies can use to cover their surplus of greenhouse gas emissions: European Union Allowances (EUAs) and Certified Emission Reductions (CERs). Both assets are traded simultaneously in several European platforms, being the European Climate Exchange

[1] In the context of emissions reduction projects, the term *PIN* is used to refer to the document which describes the initial particularities of a CDM project, known as *Project Idea Note*. In this paper, *PIN* means *Probability of Informed Trading*, as it is widely understood in market microstructure literature.

[2] It is important no mention that several papers have criticized the PIN model. See Aktas, de Bodt, Declerck and Van Oppens (2007), Boehmer, Grammig and Theissen (2007), Kaul, Lei and Stoffman (2008), Duarte and Young (2009) and Akay, Cyree, Griffiths and Winters (2012).

(ECX) the one which concentrates most of the futures contracts traded volume.[3] Our adaptation of EKOP's PIN model takes into account that informed traders can choose to trade either EUAs or CERs.

With our *ad hoc* version of the EKOPs' model, we provide evidence of the presence of informed traders in the European carbon market. CERs exhibit lower average PIN than EUAs. We also show that the PIN of the EU-ETS has changed over time. While the PIN of CERs has increased over time, together with its share in total trading activity, EUAs' PIN has remained pretty stable. Additionally, we find a significant impact of the current financial crisis on the theoretical daily opening spread for EUAs and CERs derived from our PIN model.

EKOP methodology has been previously used to study informed trading around particular non-regular events such as stock splits, mergers and acquisitions announcements, etc. (*e.g.*, Easley et al., 2001 and Aktas et al., 2007, among others). In this paper, we focus on informed trading around specific events that repeat every year in the European carbon market. By March 31st, the companies submit their emissions reports for the prior calendar year. The corresponding emission permits must be surrendered by April 30th. Finally, the European Commission publishes the information for all companies by May 15th. Consequently, each polluting company manages private information about their own emissions during several months that they can use to open profitable positions in the carbon market. Thus, if the companies anticipate they would be long (short) of permits in the future, based on their own verifications, they could sell (buy) future contracts in the market, before this information gets public. We therefore expect an increase in the PIN during the first months of each year and a sudden decrease

[3] ECX futures contracts are operated by the Intercontinental Exchange (ICE) Futures Europe, which is one of the leading markets in the negotiation of energy derivatives in Europe.

after May 15th. Consistently, we report that the PIN of EUAs regularly increases before the publication of the yearly verified-emission reports.

The remainder of the paper proceeds as follows. In section 2, we review the particularities of the European carbon market. In section 3, we examine the *traditional* PIN methodology and adapt it to fit the characteristics of the European carbon market. In section 4, we describe the database and report some descriptive statistics. In section 5, we present our empirical findings. Finally, we conclude in section 6.

2. The European Union Emissions Trading Scheme (EU-ETS)

The Directive 2003/87/EC of the European Parliament and of the European Council establishes that, as a mechanism of flexibility and in order to achieve the reduction objectives for greenhouse gasses emissions, the companies included in the directive will receive entitlements each year to cover their real verified emissions. These permits denominated European Union Allowances (EUAs) allow the owner to emit one tonne of carbon dioxide equivalent gas into the atmosphere. Nowadays, the European Union Emissions Trading Scheme (EU-ETS) is the world's largest market for carbon permits, both in terms of installations covered and volume traded.

The scheme is structured as a cap-and-trade system, where emissions are limited and any deficit or surplus can be managed through the emission allowances market. So far, the scheme has been structured in three phases. Phase I was a pilot phase and ran from 2005 to 2007; Phase II covers the period 2008 to 2012, and Phase III will last from 2013 to 2020. Under the EU-ETS, each Member State has to prepare a National Allocation Plan (NAP) 18 months prior to the start of each phase. Each Member State proposes a cap for the corresponding phase and determines if banking and borrowing facilities are allowed. Banking refers to the possibility of transferring allowances from one phase to the following phase and it was not allowed between Phases I and II, while it is possible between Phases II and III. Borrowing refers to the opposite of banking and is not allowed between phases. This implies that a Phase I EUA is a different asset than a Phase II EUA.[4] In each particular phase, banking and borrowing are both allowed within years.[5]

The 2004/101/EC Directive settles the fundaments of the project-based flexible mechanism, which authorizes EU members to generate and use Kyoto certificates in their compliance objectives. Under this directive, the Clean Development Mechanism (CDM) exposes that the countries included in Annex B of the Kyoto Protocol could exploit emissions-reduction projects in developing countries in order to generate credits, known as Certified Emission Reductions (CERs), which could be employed to meet their emissions targets. Although CERs are fully fungible with EUAs, their use is capped, with varying limits in each of the different countries (Trotignon, 2010).[6] In addition, each Member has to decide which percentage of CERs could be used instead of EUAs, as the borrowing and banking facilities for that limit within the phase.[7] Unused CERs can be transferred from Phase II to Phase III. Not all the CERs can be

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[4] As Phase I and Phase II EUAs are different assets, their prices can differ. Phase I was marked by an over-allocation of allowances. By the end of Phase I, the price of a Phase I EUA was almost zero. In contrast, since 2005 Phase II EUAs prices have moved between 34 Euros and 6.5 Euros.

[5] For a more detailed review, a complete description of the carbon market can be found in Mansanet-Bataller and Pardo (2008).

[6] Trotignon (2010) reports that this limit varies between 0% and 20%, depending on countries and sectors, with the average being about 13.5% (1,420Mt for the period 2008-2012).

[7] Concerning Phase II, in Latvia and Lithuania, which represent 7% of the potential CER imports, both borrowing and banking are prohibited. Borrowing it is also prohibited in Italy, Norway, Poland, Spain, and United Kingdom, representing 37% of the potential CER imports. In the rest of the countries (Austria, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Luxembourg, Netherlands, Portugal, Romania, Slovakia, Slovenia and Sweden), the banking and borrowing facilities are allowed. For a more detailed explanation, Trotignon (2010) presents an excellent review of all CER aspects.

used for compliance purposes. CERs generated by nuclear facilities, land use, land use changes, and forestry activities are not permitted.[8]

EUAs and CERs are fully fungible; they serve to the same purpose but they do not have the same price. CER prices should be lower than EUA prices since the use of CERs is restricted. Companies could take advantage of this fact by selling EUAs and buying CERs simultaneously, up to the established limit. Trotignon (2010) shows, however, that companies do not exploit this situation. In fact, companies are not surrendering as many CERs as they could do.

Annually, each company has to report and surrender the necessary permits to cover its verified emissions. Table I reports a timeline of the different yearly deadlines. A compliance year equals a calendar year. On February 28th, the companies receive their permits. One month later, by March 31st, each company has to submit to the European Commission the verified emissions report corresponding to the previous year. By April 30th, the permits must be surrendered. The European Commission has until May 15th, to make public those reports. Therefore, during two months (March and April), companies have allowances for two different years, so they can either use them to cover their emissions for the previous year, sell them in the market, or keep them in their own accounts.

This is the first study that deals with the design of a PIN model for the European carbon market. Nevertheless, other authors have previously analyzed trading frictions and price efficiency in the EU-ETS. Using daily data, Miclaus, Lupu, Dumitrescu and Bobirca (2008) test the impact on prices of the Phase II National Allocation Plans

[8] In Phase III, these restrictions will increase and, from 2013 onwards, all CERs generated from projects whose objective is the destruction of HFC-23 and N_2O gases cannot be used for compliance objectives. In addition, the scheme allows the Member States to bank (but not borrow) CERs from Phase II to Phase III up to a limit of 2.5% of the EUAs allocated.

(NAPs) announcements and the verified emissions reports from April 2005 to December 2007, concluding that the EUA market prices are not efficient. Daskalakis and Markellos (2008) analyze the efficiency of Powernext, NASDAQ OMX Commodities Europe, and ECX platforms through econometric testing procedures and trading strategies, concluding that these markets do not fulfill the weak-form efficiency, and Mansanet-Bataller and Pardo (2009) analyze the impact of regulatory announcements from October 2004 to May 2007, concluding that prices are affected before and during the announcement.

Using high frequency data, Benz and Hengelbrock (2008) study liquidity provision and contribution to the price discovery between ECX and NASDAQ OMX Commodities Europe using data from Phase I. Rotfuß (2009) with spot data form Bluenext and future contracts from ECX, studies the price formation and volatility in the EU-ETS. Rotfuß et al. (2009) propose a model to examine the behavior of prices before, during and after the announcements of the Phase II NAPs, and find evidence that the adjustment of EUA prices to new information is not immediate. Vinokur (2009) analyzes if there is a disposition effect in the Bluenext spot market. Bredin et al. (2011) investigate the market microstructure and trading behavior with ECX data from 2005 to 2008. Chevallier and Sévi (2011) characterize the conditional and unconditional distributions of the realized volatility present in the ECX Futures Contract with delivery in 2008. Medina et al. (2011b) analyze the history of trading frictions and market quality in the ECX using data from April 2005 to December 2010 showing that the quality of the ECX market has not remarkably changed from Phase I to Phase II. Mizrach and Otsubo (2011) analyze the market microstructure of the ECX in terms of liquidity and price discovery during 2009 and suggest that the ECX is a highly liquid market, where the price discovery takes place on the ECX futures market. Conrad et al.

(2012) model the EUA price dynamic with a GARCH model, considering the impact of the European Commission decisions regarding Phase II NAPs, and concluding that the decisions of the European Commission on second National Allocation Plans have a strong and immediate impact on EUA prices. Rittler (2012) studies the relationship between Phase II EUA futures and spot prices proving the leadership of the futures market and it increasing importance.

Finally, our PIN model explicitly models the relationship between EUAs and CERs. The existing literature has provided some mixed evidence on this relationship. Using daily data, Chevallier (2010) studies the inter-relationships between EUA and CER prices, while Mansanet-Bataller et al. (2011) analyze the spread between EUAs and CERs. Both studies conclude that EUA prices and CER prices significantly cause each, but the EUA futures market leads the price discovery. Medina et al. (2011a) use high-frequency data to end up with the same conclusion; they also conclude that the CER market may come to play a larger role in the EU-ETS. In contrast, Nazifi (2010) tests for long-term links and causal relations between EUA and CER prices with daily data, concluding that EUA and CER prices do not have a common long-run component. Similarly, Mizrach (2012) concludes that the null of no-common factors between EUA and CER prices cannot be rejected. Finally, Nazifi (2011) finds that a significant portion of the price spread between EUAs and CERs can be explained by the lack of competitiveness between markets, access constraints on the use and the availability of CERs, and the lower substitutability of CERs.

3. Methodology

3.1. The Traditional PIN Model

In the spirit of the Glosten and Milgrom (1985) sequential trade model, Easley, Kiefer and O'Hara (1996) propose a microstructure model to estimate the probability of information-based trading (PIN). In their model, liquidity providers and traders interact to exchange stocks during *I* trading periods. At the beginning of each period, an informational event could occur with probability α. These events are assumed to be independent. Given an informational event has occurred, this could be positive with probability 1-δ, or negative with probability δ. Informed traders anticipate that at the end of the day, the value of the stock will be $\underline{V_i}$ if news is bad or $\overline{V_i}$ if news is good, where $\overline{V_i} > \underline{V_i}$ and *i* is the trading period. In the model, we find two types of traders: liquidity traders who do not have private information about the true value of the asset and do not know if an informational event has occurred, and informed traders who know the true value of the asset. The uninformed market maker observes the order flow, but he is not able to distinguish between uninformed and informed traders. The market maker posts ex-post rational bid and ask quotes. After observing the arrival of orders, the liquidity provider updates its beliefs and, consequently, the prices move. During each period, orders arrive to the market according to independent Poisson processes. As there is no informative event, only uninformed traders trade, with buy and sell arrival rates ε_b and ε_s, respectively. When there is an informative event, informed traders also trade with arrival rate μ. If the signal is bad (good) news, informed traders sell (buy). Consequently, with bad (good) news, buy order flow arrives with daily intensity $\varepsilon_s+\mu$ ($\varepsilon_b+\mu$).

The trading tree presented in Figure 1 shows the structure of the trading process. Normal volume activity is due to uninformed activity, from which ε_b and ε_s can be estimated. Anomalous trading activity comes from informed trading, from which μ can be estimated. Disequilibrium is quantified along the different periods, from which α and δ can be estimated too. Via maximum likelihood, the model can be estimated and the unobservable parameters $\theta = (\alpha, \delta, \mu, \varepsilon_b, \varepsilon_s)$ obtained. In particular, the likelihood function for one single day "*i*" is defined as

$$\begin{aligned} f(B_i, S_i|\theta) &= \alpha\delta\exp(-\varepsilon_b)\frac{\varepsilon_b^{B_i}}{B_i!}\exp[-(\varepsilon_s+\mu)]\frac{(\varepsilon_s+\mu)^{S_i}}{S_i!} + \alpha(1-\delta)\exp[-(\varepsilon_b+\mu)]\frac{(\varepsilon_b+\mu)^{B_i}}{B_i!}\exp(-\varepsilon_s)\frac{\varepsilon_s^{S_i}}{S_i!} \\ &+ (1-\alpha)\exp(-\varepsilon_b)\frac{\varepsilon_b^{B_i}}{B_i!}\exp(-\varepsilon_s)\frac{\varepsilon_s^{S_i}}{S_i!} \end{aligned} \quad (1)$$

where B_i is the total number of buyer-initiated trades on day *i* and S_i the total number of seller-initiated trades. Since days are assumed to be independent, the estimation of the parameters for a period of *I* days, can be obtained by maximizing the product of the daily likelihoods. The resultant likelihood function to maximize is defined as $L(D|\theta) = \prod_{i=1}^{I} f(B_i, S_i|\theta)$ where $D = (B_i, S_i)_{i=1}^{I}$, $\alpha, \delta \in [0,1]$ and $\mu, \varepsilon_b, \varepsilon_s \in [0, \infty)$.

EKOP derive the unconditional probability of informed-based trading, defined as $PIN = \frac{\alpha\mu}{\alpha\mu + \varepsilon_b + \varepsilon_s}$ where $\alpha\mu+\varepsilon_b+\varepsilon_s$ represents the expected order flow, and $\alpha\mu$ the expected informed order flow. This ratio converges to high values when there are big and infrequent jumps in the number of trades, while frequent jumps lead with low PIN values.

3.2. *The PIN of the European Carbon Market*

In this section, we adapt the *traditional* PIN methodology to the case of the European carbon market. Informed and uninformed traders have the possibility to trade two related assets: EUAs and CERs. As previously discussed, their price cannot be equal, but they must share a common long-run component. Our model extends the basic PIN model by allowing traders to choose between EUAs and CERs. In Figure 2, we present the probability tree of the trading model for the European carbon market. The difference with the *traditional* PIN model is that, in this case, traders can operate with two different, but linked, assets. In this case, *β (1- β)* is the fraction of informed traders trading CER (EUA) contracts, *τ (1-τ)* is the fraction of uninformed traders buying CER (EUA) contracts and *φ (1-φ)* is the fraction of uninformed traders selling CER (EUA) contracts.

In this context, the likelihood function of orders arrivals for one single day would be defined by

$$f\left(B_i^{EUA},S_i^{EUA},B_i^{CER},S_i^{CER}\middle|\theta\right)=\alpha\cdot\delta\cdot BE+\alpha\cdot\left(1-\delta\right)\cdot GE+\left(1-\alpha\right)\cdot NE \tag{2}$$

where $\theta=\left(\alpha,\delta,\beta,\tau,\varphi,\mu,\varepsilon_b,\varepsilon_s\right)$, B_i^{EUA} represents the number of initiated buy orders trading EUAs, S_i^{EUA} represents the number of initiated sell orders trading EUAs, B_i^{CER} represents the number of initiated buy orders trading CERs, and finally S_i^{CER} represents the number of initiated sell orders trading CERs.

In (2),

$$\begin{aligned}BE=&\exp\left[-\left(1-\tau\right)\varepsilon_b\right]\frac{\left[\left(1-\tau\right)\varepsilon_b\right]^{B_i^{EUA}}}{B_i^{EUA}!}\exp\left[-\left(\left(1-\varphi\right)\varepsilon_s+\left(1-\beta\right)\mu\right)\right]\frac{\left[\left(1-\varphi\right)\varepsilon_s+\left(1-\beta\right)\mu\right]^{S_i^{EUA}}}{S_i^{EUA}!}\exp\left(-\tau\varepsilon_b\right)\frac{\left(\tau\varepsilon_b\right)^{B_i^{CER}}}{B_i^{CER}!}\\&\cdot\exp\left[-\left(\varphi\varepsilon_s+\beta\mu\right)\right]\frac{\left(\varphi\varepsilon_s+\beta\mu\right)^{S_i^{CER}}}{S_i^{CER}!}\end{aligned} \tag{3}$$

stands for the likelihood of executed orders on a bad-event day;

$$\begin{aligned}GE=&\exp\left[-\left(\left(1-\tau\right)\varepsilon_b+\left(1-\beta\right)\mu\right)\right]\frac{\left[\left(1-\tau\right)\varepsilon_b+\left(1-\beta\right)\mu\right]^{B_i^{EUA}}}{B_i^{EUA}!}\exp\left[-\left(1-\varphi\right)\varepsilon_s\right]\frac{\left[\left(1-\varphi\right)\varepsilon_s\right]^{S_i^{EUA}}}{S_i^{EUA}!}\\&\cdot\exp\left[-\left(\tau\varepsilon_b+\beta\mu\right)\right]\frac{\left(\tau\varepsilon_b+\beta\mu\right)^{B_i^{CER}}}{B_i^{CER}!}\exp\left(-\varphi\varepsilon_s\right)\frac{\left(\varphi\varepsilon_s\right)^{S_i^{CER}}}{S_i^{CER}!}\end{aligned} \tag{4}$$

is the likelihood of executed orders on a good-event day and, finally,

$$NE = \exp\left[-(1-\tau)\varepsilon_b\right]\frac{\left[(1-\tau)\varepsilon_b\right]^{B_i^{EUA}}}{B_i^{EUA}!}\exp\left[-(1-\varphi)\varepsilon_s\right]\frac{\left[(1-\varphi)\varepsilon_s\right]^{S_i^{EUA}}}{S_i^{EUA}!}\exp(-\tau\varepsilon_b)\frac{(\tau\varepsilon_b)^{B_i^{CER}}}{B_i^{CER}!}\exp(-\varphi\varepsilon_s)\frac{(\varphi\varepsilon_s)^{S_i^{CER}}}{S_i^{CER}!} \quad (5)$$

is the likelihood of executed orders on a day with no event.

The estimation of the parameters can be obtained by maximizing the product of the daily likelihoods, $L(D|\theta) = \prod_{i=1}^{I} f\left(B_i^{EUA}, S_i^{EUA}, B_i^{CER}, S_i^{CER}|\theta\right)$ where $D = \left(B_i^{EUA}, S_i^{EUA}, B_i^{CER}, S_i^{CER}\right)_{i=1}^{I}$, $\alpha,\delta,\beta,\tau,\varphi \in [0,1]$ and $\mu,\varepsilon_b,\varepsilon_s \in [0,\infty)$.

In order to reduce convergence problems in the estimations, because of numerical overflow, when the number of buys and sells is very large we use the approach described in Appendix A.[9]

As a result, the derived PINs, which are the percentage of informed trading over the total orders, are defined as:

$$PIN_{EUA} = \frac{\alpha(1-\beta)\mu}{\alpha(1-\beta)\mu + (1-\tau)\varepsilon_b + (1-\varphi)\varepsilon_s} \quad (6)$$

$$PIN_{CER} = \frac{\alpha\beta\mu}{\alpha\beta\mu + \tau\varepsilon_b + \varphi\varepsilon_s} \quad (7)$$

The characteristics of our trading tree, allow us to define an individual PIN measure for EUAs in (6) and CERs in (7). In both cases the numerator represents the informed trading activity and the denominator the total trading activity, of the corresponding asset.

3.3. *The opening bid-ask spread*

Easley, O'Hara and Saar (2001) and Easley, Hvidkjaer and O'Hara (2002) propose an approach to estimate the theoretical opening bid-ask spread through the

[9] For more details see Duarte and Young (2009).

estimated parameters of the PIN model in section 3.1. Denote $\underline{V_i}$ as the value at the end of day when bad news is revealed, $\overline{V_i}$ as the value at the end with good news and V_i^* as the expected value of a day without information, $V_i^* = \delta \underline{V_i} + (1-\delta)\overline{V_i}$. Considering that the market maker beliefs at time *t* are given by the probabilities of no event $P_n(t)$, good event $P_g(t)$ and bad event $P_b(t)$, conditioned by the history prior to *t* the expected value of the asset on day *i* is $E[V_i|t] = P_n(t)V_i^* + P_b(t)\underline{V_i} + P_g(t)\overline{V_i}$.

At time *t*, the zero profit bid price should be

$$b(t) = E[V_i|t] - \frac{\mu P_b(t)}{\varepsilon_s + \mu P_b(t)}\left(E[V_i|t] - \underline{V_i}\right) = E[V_i|t] - \frac{\mu\alpha\delta}{\varepsilon_s + \mu\alpha\delta}\left(E[V_i|t] - \underline{V_i}\right) \tag{8}$$

which is the expected value conditioned on the history arrival of selling orders. In a similar way, the ask price of the asset is

$$a(t) = E[V_i|t] + \frac{\mu P_g(t)}{\varepsilon_b + \mu P_g(t)}\left(\overline{V_i} - E[V_i|t]\right) = E[V_i|t] + \frac{\mu\alpha(1-\delta)}{\varepsilon_b + \mu\alpha(1-\delta)}\left(\overline{V_i} - E[V_i|t]\right) \tag{9}$$

The theoretical relative spread will be defined as

$$S^{TH} = \frac{\Sigma(0)}{V^*} = \mu\sqrt{\alpha\delta(1-\delta)}\left[\frac{1}{\varepsilon_b + \mu\alpha(1-\delta)} + \frac{1}{\varepsilon_s + \mu\alpha\delta}\right]\sigma_V \tag{10}$$

where σ_V is the standard deviation of the percentage changes in the price of the asset.[10] Easley, O'Hara and Saar (2001) pointed out that this standard deviation could be seen as the market makers' possible losses for trading with informed traders, while the rest of the parameters symbolize the probability of trading with an informed trading.

Similarly, we can obtain the theoretical opening spreads for the carbon market model. As we consider two assets in the model, we will obtain two theoretical opening

[10] Following Easley, O'Hara and Saar (2001), we calculate the standard deviation of the daily percentage changes in the value of the stock, as the standard deviation of the percentage difference between the daily closing price and the daily opening price.

spreads. All in all, the bid and ask prices for both EUAs and CERs would be the following:

$$b(t)_{EUA} = E\left[V_i^{EUA}\middle|t\right] - \frac{\mu(1-\beta)P_b(t)}{(1-\varphi)\varepsilon_s + \mu(1-\beta)P_b(t)}\left(E\left[V_i^{EUA}\middle|t\right] - \underline{V_i^{EUA}}\right) = \\ = E\left[V_i^{EUA}\middle|t\right] - \frac{\mu(1-\beta)\alpha\delta}{(1-\varphi)\varepsilon_s + \mu(1-\beta)\alpha\delta}\left(E\left[V_i^{EUA}\middle|t\right] - \underline{V_i^{EUA}}\right) \quad (11)$$

$$a(t)_{EUA} = E\left[V_i^{EUA}\middle|t\right] + \frac{\mu(1-\beta)P_g(t)}{(1-\tau)\varepsilon_b + \mu(1-\beta)P_g(t)}\left(\overline{V_i^{EUA}} - E\left[V_i^{EUA}\middle|t\right]\right) = \\ = E\left[V_i^{EUA}\middle|t\right] + \frac{\mu(1-\beta)\alpha(1-\delta)}{(1-\tau)\varepsilon_b + \mu(1-\beta)\alpha(1-\delta)}\left(\overline{V_i^{EUA}} - E\left[V_i^{EUA}\middle|t\right]\right) \quad (12)$$

$$b(t)_{CER} = E\left[V_i^{CER}\middle|t\right] - \frac{\mu\beta P_b(t)}{\varphi\varepsilon_s + \mu\beta P_b(t)}\left(E\left[V_i^{CER}\middle|t\right] - \underline{V_i^{CER}}\right) = \\ = E\left[V_i^{CER}\middle|t\right] - \frac{\mu\beta\alpha\delta}{\varphi\varepsilon_s + \mu\beta\alpha\delta}\left(E\left[V_i^{CER}\middle|t\right] - \underline{V_i^{CER}}\right) \quad (13)$$

$$a(t)_{CER} = E\left[V_i^{CER}\middle|t\right] + \frac{\mu\beta P_g(t)}{\tau\varepsilon_b + \mu\beta P_g(t)}\left(\overline{V_i^{CER}} - E\left[V_i^{CER}\middle|t\right]\right) = \\ = E\left[V_i^{CER}\middle|t\right] + \frac{\mu\beta\alpha(1-\delta)}{\tau\varepsilon_b + \mu\beta\alpha(1-\delta)}\left(\overline{V_i^{CER}} - E\left[V_i^{CER}\middle|t\right]\right) \quad (14)$$

Expressions (11) and (12) show the bid and ask prices for the EUA contracts posted by the market maker, taking into account all the available history of the orders arrivals. Expressions (13) and (14) present the corresponding bid and ask quotes for the CER contract.

In this sense, the spread for the EUA contract is determined by

$$\Sigma(t)_{EUA} = a(t)_{EUA} - b(t)_{EUA} = \frac{\mu(1-\beta)\alpha(1-\delta)}{(1-\tau)\varepsilon_b + \mu(1-\beta)\alpha(1-\delta)}\left(\overline{V_i^{EUA}} - E\left[V_i^{EUA}\middle|t\right]\right) + \frac{\mu(1-\beta)\alpha\delta}{(1-\varphi)\varepsilon_s + \mu(1-\beta)\alpha\delta}\left(E\left[V_i^{EUA}\middle|t\right] - \underline{V_i^{EUA}}\right) = \\ = \frac{\mu(1-\beta)\alpha(1-\delta)}{(1-\tau)\varepsilon_b + \mu(1-\beta)\alpha(1-\delta)}\left(\overline{V_i^{EUA}} - \delta\underline{V_i^{EUA}} - (1-\delta)\overline{V_i^{EUA}}\right) + \frac{\mu(1-\beta)\alpha\delta}{(1-\varphi)\varepsilon_s + \mu(1-\beta)\alpha\delta}\left(\delta\underline{V_i^{EUA}} + (1-\delta)\overline{V_i^{EUA}} - \underline{V_i^{EUA}}\right) = \\ = \frac{\mu(1-\beta)\alpha(1-\delta)}{(1-\tau)\varepsilon_b + \mu(1-\beta)\alpha(1-\delta)}\left(\delta\left(\overline{V_i^{EUA}} - \underline{V_i^{EUA}}\right)\right) + \frac{\mu(1-\beta)\alpha\delta}{(1-\varphi)\varepsilon_s + \mu(1-\beta)\alpha\delta}\left((1-\delta)\left(\overline{V_i^{EUA}} - \underline{V_i^{EUA}}\right)\right) = \\ = \mu(1-\beta)\alpha\delta(1-\delta)\left[\frac{1}{(1-\tau)\varepsilon_b + \mu(1-\beta)\alpha(1-\delta)} + \frac{1}{(1-\varphi)\varepsilon_s + \mu(1-\beta)\alpha\delta}\right]\left(\overline{V_i^{EUA}} - \underline{V_i^{EUA}}\right) \quad (15)$$

while the theoretical opening spread would be defined as

$$S_{EUA}^{TH} = \frac{\Sigma(0)}{V^*} = \mu(1-\beta)\sqrt{\alpha\delta(1-\delta)}\left[\frac{1}{(1-\tau)\varepsilon_b + \mu(1-\beta)\alpha(1-\delta)} + \frac{1}{(1-\varphi)\varepsilon_s + \mu(1-\beta)\alpha\delta}\right]\sigma_{V_{EUA}} \quad (16)$$

The spread for the CER contract would be defined by

$$\begin{aligned}
\Sigma(t)_{CER} &= a(t)_{CER} - b(t)_{CER} = \frac{\mu\beta\alpha(1-\delta)}{\tau\varepsilon_b + \mu\beta\alpha(1-\delta)}\left(\overline{V_i^{CER}} - E\left[V_i^{CER}\middle|t\right]\right) + \frac{\mu\beta\alpha\delta}{\varphi\varepsilon_s + \mu\beta\alpha\delta}\left(E\left[V_i^{CER}\middle|t\right] - \underline{V_i^{CER}}\right) = \\
&= \frac{\mu\beta\alpha(1-\delta)}{\tau\varepsilon_b + \mu\beta\alpha(1-\delta)}\left(\overline{V_i^{CER}} - \delta\underline{V_i^{CER}} - (1-\delta)\overline{V_i^{CER}}\right) + \frac{\mu\beta\alpha\delta}{\varphi\varepsilon_s + \mu\beta\alpha\delta}\left(\delta\underline{V_i^{CER}} + (1-\delta)\overline{V_i^{CER}} - \underline{V_i^{CER}}\right) = \\
&= \frac{\mu\beta\alpha(1-\delta)}{\tau\varepsilon_b + \mu\beta\alpha(1-\delta)}\left(\delta\left(\overline{V_i^{CER}} - \underline{V_i^{CER}}\right)\right) + \frac{\mu\beta\alpha\delta}{\varphi\varepsilon_s + \mu\beta\alpha\delta}\left((1-\delta)\left(\overline{V_i^{CER}} - \underline{V_i^{CER}}\right)\right) = \\
&= \mu\beta\alpha\delta(1-\delta)\left[\frac{1}{\tau\varepsilon_b + \mu\beta\alpha(1-\delta)} + \frac{1}{\varphi\varepsilon_s + \mu\beta\alpha\delta}\right]\left(\overline{V_i^{CER}} - \underline{V_i^{CER}}\right)
\end{aligned} \tag{17}$$

and the theoretical opening spread would be calculated as

$$S_{CER}^{TH} = \frac{\Sigma(0)}{V^*} = \mu\beta\sqrt{\alpha\delta(1-\delta)}\left[\frac{1}{\tau\varepsilon_b + \mu\beta\alpha(1-\delta)} + \frac{1}{\varphi\varepsilon_s + \mu\beta\alpha\delta}\right]\sigma_{V_{CER}} \tag{18}$$

Both expressions (16) and (18) would be employed in our work to analyze how the opening spreads have developed over time.

4. The data

We use high frequency and daily data obtained from the ICE ECX Platform, covering the period from March 14th, 2008, the day CERs began to quote in ECX, to December 31st, 2011.

Our dataset contains all trades registered in the ECX for EUA and CER futures contracts. For each trade, the database reports the time stamp (to the nearest second), the price (in Euros), the volume (in lots), the sign (buyer- or seller-initiated) and the trade type.[11] In our analysis, we will focus only on screen (ordinary) trades.

[11] Screen-trade orders (or regular orders) are the most common trades in the ECX. During the period 2008-2010 represented around 83% of the total number of trades registered in the ECX. The rest of the orders (Screen Cross trades (same clearing member), On-screen corrections, Block trades, Exchange for Physical (EFP)/Exchange for Swap (EFS) trades, Bilateral off-exchanges and Settlement trades) have a residual importance.

Table II presents several sample descriptive statistics for all December futures contracts with maturities between 2008 and 2014, for both EUAs and CERs. Panel A (B) presents the statistics for the EUA (CER) futures contracts. In general, the number of trades for EUA contracts exceeds by far the number of trades for CER contracts; however, CER volume per trade is twice the EUA volume for both December 2008 and 2009 contracts, similar for both December 2010 and 2011 contracts, and the half for both December 2013 and 2014 contracts. Paying attention to the maximum number of trades in a day, the measure shows an increase over time, for both EUAs and CERs.[12] Table II also shows that the EUA (CER) December 2011 (2012) contract is the most traded one, followed by the EUA (CER) December 2010 (2011) contract. Nevertheless, these results are distorted by the fact that these contracts consider more trading days than the rest. Finally, it is remarkable that although the database finishes in 2011, CER December 2012 contract is the most traded one (and not December 2011 contract), highlighting the importance the end of Phase II has on CERs contracts.

Figure 3 plots the average number of trades for all December futures contracts. Panel A in Figure 3 plots the evolution for the EUA contracts. In general, the monthly number of trades has been increasing since 2008. In addition, the trading activity increases during the months of April and May and then decreases as it approaches the end of the year. Nevertheless, this pattern changed during 2011, where we distinguish an increase of the volume during June, July August and November, coinciding with the announcements of several news related to Phase III. Panel B plots a different sequence for the CER contracts. The number of trades per month has also increased since 2008, and shows no seasonality during April and May. Figure 3 suggests that EUA trading

[12] We pay attention to the maximum number of trades in a day instead of the average or the median, because in further maturities these statistics are affected by days in which the contracts are not the front contract one and their volumes are very low. If we focus on the trading activity for the period where each contract acts as the front contract we corroborate, for both EUAs and CERs contracts, the increase of the trading activity over time.

activity concentrates in April and May, while CER volume increases as the contract approaches maturity.

Our methodology requires the use of continuous time series. Since futures contracts have a finite life, we generate single time series by rolling over contracts using the "last day criterion".[13] This criterion switches from one contract to another on the expiry date of the first one. For our analysis, we consider 3 rollover series for each asset (EUAs and CERs): considering the front contract, the second nearest delivery contract, and the third nearest delivery contract. Table III displays the different rollover dates.

5. Empirical findings

5.1. Seasonality patterns of the PIN in the European carbon market

In this sub-section we estimate a unique PIN per month, in order to identify a possible pattern on the informed trading activity along the year. We estimate a weighted PIN per calendar month, using the front contract rollover series. Thus, April's PIN estimation is obtained using data from April 2008 (EUA and CER December 2008 contracts), April 2009 (EUA and CER December 2009 contract), April 2010 (EUA and CER December 2010 contracts) and April 2011 (EUA and CER December 2011 contracts). We fix α and δ, along the different years, leaving the "order intensity" parameters (μ, ε_b, ε_s) and the "ratio" parameters (β, τ, φ) free for the different years.

Figure 4 plots the estimated α and the PINs for both EUAs and CERs, for each month. The PIN measures have been calculated as an aggregate of the different informed trading behaviors observed in each month, for the different years. The following expressions illustrate the method:

[13] Carchano, Medina and Pardo (2012) conclude that there are no statistical differences in using the "last day criterion" or other different criteria, in both EUAs and CERs series, using December contracts.

$$PIN_{EUA}^{total} = \frac{\alpha \sum_{m=1}^{M} (1-\beta_m)\mu_m}{\alpha \sum_{m=1}^{M} (1-\beta_m)\mu_m + \sum_{m=1}^{M} (1-\tau_m)\varepsilon_b^m + \sum_{m=1}^{M} (1-\varphi_{tm})\varepsilon_s^m} \quad (19)$$

$$PIN_{CER}^{total} = \frac{\alpha \sum_{m=1}^{M} \beta_m \mu_m}{\alpha \sum_{m=1}^{M} \beta_m \mu_m + + \sum_{m=1}^{M} \tau_m \varepsilon_b^m + \sum_{m=1}^{M} \varphi_m \varepsilon_s^m} \quad (20)$$

with M being the number of years considered for each month. Expression (19) corresponds to EUA's PIN and expression (20) corresponds to CER's PIN.[14]

Firstly, as expected, the PIN for EUAs exhibits higher values before the emissions reports are made public. Before March 31st, polluting companies can take advantage of the private information they manage about their actual emissions. Between March 31st and May 15th, several reports could be made public and by May 15th all the information is available. The highest PIN values correspond to December and March. December is the end of the compliance year and coincides with the maturity of the relevant futures contract. March corresponds to the last month before the verified emissions reports are submitted. PIN steadily increases from January to March. Then, decreases until October when it starts to increase again until December. Finally, it is interesting to highlight that although most of the EUA volume is traded during April and May (see Figure 3a), informed trading concentrates on the preceding months. According to Admati and Pfleiderer (1988) seminal work, both liquidity-motivated and informed traders prefer to trade when the market is "thick" (trading has little effect on prices). Liquidity traders have incentives to trade all together to avoid big movements on prices and diminish the probability of trading with informed traders, while informed traders can hide their activity better. Actual emissions information in the EU-ETS starts

[14] Because of the available sample, both January and February estimations consider only data from years 2009, 2010 and 2011, while the rest of the months include data from 2008 to 2011 in the estimation.

being public during April and May. Therefore, our findings suggest that liquidity traders enter the market when the probability of trading with informed traders has decreased. However, because informed traders also operate when uninformed traders do so, the PIN remains high during April and May. From December to March liquidity traders do not have incentives to trade, as informed traders are acting on the market. This behavior leaves lower trading volumes, but higher PIN levels.

The CER PIN shows a different pattern. It is more volatile and increases as we approach the end of the year. This behavior could be explained by companies delaying the trading of CERs, until they know exactly their needs for the year (see Figure 3b). CER users are not usually CER producers, but they do own EUAs. So, if they want to use CERs they have two options: either they trade the corresponding December contract before the delivery day or they have to buy CERs in the spot market. As the spot market is not very liquid, informed traders, in order to hide their position, would prefer to trade in the futures market, rather than in the spot market, thereby increasing the futures contracts trading activity and their PIN levels (see Figure 4). In addition, CERs show lower PIN levels in January, February and March, than at the end of the year, although most of the private information concentrates in the first quarter of each year. During these months informed traders probably prefer to focus on EUA contracts, as these are more liquid than CER contracts. These results are consistent with Chowdhry and Nanda (1991).

Finally, α achieves its maximum value in April. This fact should not come as a surprise. Between March 31st and May 15th, the emissions reports have been submitted to the European Commission, but have not yet been officially published. If any report is leaked before May 15th, an informational event takes place. Although the pattern is stable, we can distinguish a negative trend from April to September and a positive trend from September to April.

5.2. Time evolution of PIN in the European carbon market

The PIN patterns observed in Figure 4 suggest that a good division for our time evolution analysis could be to split each year into natural quarters: January-March, April-June and July-September and October-December.[15]

In this sub-section, we estimate the PIN for each calendar quarter in the period April 1st, 2008 to December 31st, 2011, by including in a joint-estimation, data for the three nearest December rollover series for each asset. In the joint-estimation, we fix again α and δ along the different rollover series, as these parameters should be common to all futures contracts in the market.[16] The results are presented in Figure 5.

Figure 5a plots the evolution of α and δ. In general, α and δ exhibit two different trends. The first one shows a slightly negative trend, suggesting that informational events are less likely over time, although the variable seems to be pretty stable. This fact could be interpreted as the market is maturing and that informational events appear less often. The case of δ is different; the variable presents a positive trend, but with higher volatility. The high values during 2010 and 2011 could reflect the negative market perception (market is long on EUAs) and the scandals (robbery of permits from members' accounts, VAT frauds, phishing attacks and cyber-attacks against the emission allowance registries of EU Member States), which occurred over those years.

Figure 5b presents the *aggregated* PINs. As we did in the seasonality analysis, we have calculated a PIN for the EUA contracts and another for the CER contracts. In

[15] This division coincides with the one chosen in Medina et al. (2011b), making it easier to compare our results with their findings.

[16] In the estimation we eliminated four outliers from the front contract rollover series. The deleted outliers correspond to the following days: 3/15/11, 6/21/11, 6/23/11 and 12/20/11.

each estimation, we have taken into account the three nearest maturity rollover series. Simplifying, our PINs are defined as:

$$PIN_{EUA}^{aggregated} = \frac{\alpha \sum_{n=1}^{N} (1-\beta_n)\mu_n}{\alpha \sum_{n=1}^{N} (1-\beta_n)\mu_n + \sum_{n=1}^{N} (1-\tau_n)\varepsilon_b^n + \sum_{n=1}^{N} (1-\varphi_n)\varepsilon_s^n} \quad (21)$$

$$PIN_{CER}^{aggregated} = \frac{\alpha \sum_{n=1}^{N} \beta_n \mu_n}{\alpha \sum_{n=1}^{N} \beta_n \mu_n + + \sum_{n=1}^{N} \tau_n \varepsilon_b^n + \sum_{n=1}^{N} \varphi_n \varepsilon_s^n} \quad (22)$$

Expressions (21) and (22) present the formulas for both the *aggregated* EUA PIN and the *aggregated* CER PIN. "*n*" symbolizes the rollover series: "1" being the front contracts rollover series; "2" the second nearest maturity rollover series, and "3" the third nearest maturity rollover series.

Figure 5b plots a volatile pattern for the EUA PIN, with a stable trend, suggesting that informed trading on EUA contracts has maintained stable over time. The case of CERs is different as its trend is clearly positive, but with values below those exhibited by the EUAs. The average PINs for EUAs and CERs are 0.159522 and 0.113869, respectively. We reject the equality of means (t-test) and medians (Kruskal-Wallis test) at the 5% level. Nevertheless, in the last 3 quarters of 2011 this gap converged to almost zero, which could suggest that informed trading is starting to focus its activity, not only on EUA, but also on CERs. Another possible explanation could be that a lot of news concerning CERs, specifically concerning Phase III CERs, appeared during 2010 and 2011, thereby increasing the amount of news in the CER market, and consequently, the informed trading activity of this asset.

Similarly, Figure 5c plots in this case the PINs per rollover series. In the Figure, "Dec T" refers to the front December rollover series, "Dec T+1" refers to the second nearest maturity December rollover series, and "Dec T+2" refers to the third nearest maturity December rollover series. In general, the nearest maturity series seem to exhibit lower PINs than the rest, moreover, the longer the maturity is, the higher the PIN levels are, although this effect is more appreciable in the EUA series. EUAs show higher PINs than CERs.[17] Additionally, PINs in longer maturities have been decreasing over time. A possible explanation could be that the volume in these contracts has increased over time (see Figure 3) and informed trading could have been losing importance in favor of uninformed orders. Focusing on the PIN volatility, on the one hand, EUA rollover series seem to show less volatility levels than CERs, but equality tests of variances (Brown-Forsythe test) reject this possibility. On the other hand, the volatility is higher in longer maturities.[18] Finally, the EUA PIN for the nearest maturity rollover presents a very stable trend, while the other two EUA series show a negative slope. CER behavior is different and, although the volatility is higher, in all three contracts we observe a positive trend. These last results are in accordance with what we observed in Figure 5b.

In Figure 5d, β, τ and φ parameters are presented. In general, β, for all three rollover series, exhibits lower values than τ and φ, indicating that informed traders

[17] The average PINs for the EUA (CER) rollover series are 0.136568 (0.084875), 0.248974 (0.101213) and 0.319906 (0.210743), for the nearest maturity, the second nearest and the third nearest maturity series, respectively. Equality tests of means (t-test) and medians (Kruskal-Wallis test) reject the similarities between the rollover series, at the 5% level, with three exceptions; we cannot reject the equality of both means and medians, when we compare the CER front contract rollover series and the CER second nearest rollover series, and the equality of medians when we compare the EUA second and third nearest maturity series.

[18] The PIN standard deviations for the EUA (CER) rollover series are 0.022920 (0.037318), 0.069031 (0.075187) and 0.103985 (0.167398), for the nearest maturity, the second nearest and the third nearest maturity series, respectively. Equality tests of variances (Brown-Forsythe test) reject the similarities between series, at the 5% level, with two exceptions; we cannot reject the equality of variances between the second and the third nearest rollover series, for both EUAs and CERs.

prefer trading EUAs to CERs.[19] If informed trading concentrates on EUAs, it is not surprising that EUAs lead price discovery.

In addition, we report an unusual behavior in the first quarter of 2009. Medina et al. (2011b) observe a decrease in liquidity during that quarter they attribute to the consequences of the financial crisis. During that period, and in order to obtain cash, many companies sold EUAs (spot) and bought EUA futures contracts, concentrating trading activity onto EUAs.[20] This unusual activity generated an increase in EUA volume, negatively affecting market liquidity and widening the differences in prices between contracts.

Figure 5e plots μ, ε_b and ε_s behavior. As we expected, the front contract series variables show the increases in volume reported during the second quarter (April and May) of each year (see Figure 3), while in the other two rollover series, the picture changes and the positive trend suggests a systematic increase in volume for further December contracts. This increase could affect the weight of informed trading in the total activity, diminishing its influence. This fact corroborates the negative trend found in the PINs of these rollover series. In addition, equality tests in means and medians do not reject the equality of μ, towards ε_b and ε_s in our three rollover series.[21] In order to compare the relative influence of μ, we plot the percentage of informed trading, defined as $\frac{\mu}{\mu+\varepsilon_b+\varepsilon_s}$. Figure 5f plots this quotient for our three rollover series. The results

[19] The average values for β are 0.037680, 0.078405 and 0.137026, for the nearest, the second nearest and the third nearest maturity cases, respectively, while the average values for τ (φ) are 0.061113 (0.061092), 0.174525 (0.161340) and 0.209509 (0.214686), for the nearest, the second nearest and the third nearest maturity cases, respectively. Equality tests of means (t-test) and medians (Kruskal-Wallis test) reject the similarities between β and τ, and β and φ, at the 5% level, with two exceptions; when we compare β towards both τ and φ, for the third nearest rollover series.

[20] During the 4th quarter of 2008, the median of the daily ratio between the EUAs volume and the total volume, for the nearest maturity rollover series, was 92.1184%, while during the 1st quarter of 2009 the ratio was 96.5705%. We reject the equality of medians (Kruskal-Wallis test) and means (t-test) at the 5% level, proving an increase in the EUAs trading activity over the total trading activity, during the first quarter of 2009.

[21] We reject the equality of means (t-test) and medians (Kruskal-Wallis test), at the 5% level, in all cases.

exhibit lower ratios of informed trading on nearest maturity contracts,[22] although the differences have narrowed over time.[23]

We conclude this section by contrasting three hypotheses regarding the model employed. Firstly, we will test whether $\tau=\varphi$. Failing to reject this hypothesis would imply that both uninformed buy and sell orders trade CERs and EUAs in the same proportion. Our second hypothesis claims that β, τ and φ are equal throughout the three rollover series, meaning that informed do not have preferences between contracts. The third hypothesis combines the previous two.

In order to test the hypotheses, we have carried out a chi-test, by comparing the likelihoods of the respective restricted and unrestricted models. The results clearly show a rejection of all three hypotheses, in all the analyzed quarters, at the 5% level. These results suggest that both informed and uninformed traders behave differently depending on the maturity of the contract, and in addition, uninformed orders are also conditioned to their sign, consistent with Lei and Wu (2005).[24]

5.3. *The theoretical opening spread*

Figure 6 plots the theoretical opening spread for both EUAs and CERs, and for all three rollover series. Figure 6a plots the evolution for the three EUA rollover series. All three series present positive trends between the second quarter of 2008 and the first quarter of 2009. This increase could be explained by the financial crisis, where many companies sold spot and acquired futures contracts, dramatically affecting market liquidity (see Medina et al. (2011b)). From the peak of 2009 until the fourth quarter of

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[22] The means for the percentage of informed trading are 0.289831, 0.436567 and 0.519641, for the nearest, the second nearest and the third nearest maturity series, respectively. In all cases, we reject the equality of means (t-test) and medians (Kruskal-Wallis test), between series, at the 5% level.

[23] In order to obtain robustness, we repeated the analysis with the spot contracts, obtaining similar results, with higher PINs and lower levels of μ, ε_b and ε_s. These results are available upon request.

[24] These results are not included for the sake of brevity, but are available from authors upon request.

2010, we report a decrease in the spread, but the fourth quarter of 2010 is also an inflexion point, where the spreads started to increase again because of the doubts of the market and the fall in prices.

The front rollover series shows the lowest spreads, followed by the second nearest maturity series and the third one, respectively. The average spreads for the EUAs rollover series are 0.9980%, 1.6672% and 2.0051% for the nearest maturity, the second nearest and the third nearest maturity series, respectively.[25] There is a certain convergence between the spreads, especially towards the fourth quarter of 2010, but from that moment on, the differences increase again. Finally, the volatility of the spread seems to be lower in the front contract series than in the other two series, maybe because of the noise of the series. The standard deviation of the opening spreads for the EUAs rollover series are 0.3971%, 0.7166% and 0.9774% for the nearest maturity, the second nearest and the third nearest maturity series, respectively.[26]

CER spreads exhibit a different pattern (see Figure 6b), keeping quite stable over time and only exhibiting a peak in the first quarter of 2009 for the third nearest maturity series. Nevertheless, like EUAs, the spread increases in 2011 for all three series, perhaps because of the financial crisis, the subsequent fall in prices and the PIN increase. Comparing among the series, the average spreads for the CERs rollover series are 0.5193%, 0.6267% and 1.0514% for the nearest maturity, the second nearest and the third nearest maturity series, respectively.[27] Focusing on 2011, the nearest maturity

[25] We reject the equality of means (t-test) and medians (Kruskal-Wallis test) between the nearest maturity rollover series and both the second and the third nearest maturity series, at the 5% level, but we cannot reject the equality of means and medians between the second and the third nearest maturity series, at the 5% level.

[26] We reject the equality of variances (Brown-Forsythe test) between the nearest maturity rollover series and both the second and the third nearest maturity series, at the 5% level, but we cannot reject the equality of variances between the second and the third nearest maturity series, at the 5% level.

[27] We cannot reject the equality of means (t-test) and medians (Kruskal-Wallis test), between the different rollover series, at the 5% level.

series shows lower spreads than the further maturity series. The front maturity series seems to show also less volatility in the spread than the other two series. The standard deviation of the theoretical opening spreads for the CERs rollover series are 0.260367%, 0.561156% and 0.994281% for the nearest maturity, the second nearest and the third nearest maturity series, respectively.[28]

If we now compare between EUAs and CERs, in general, CER spreads show lower values than EUA spreads.[29] This result could be surprising because CERs are less traded than EUAs, but they are reflecting the higher PIN levels of EUAs compared to CERs. In general, EUAs and CERs spreads show different behaviors before 2011, the moment when both series start a positive trend, and their spreads and PINs start to converge, especially for the front contract rollover series. We cannot reject significant differences between the variances (Brown-Forsythe test) of both EUAs and CERs rollover series, at the 5% level.[30]

6. Summary and conclusions

In this paper we have studied the Probability of Informed Trading (PIN) of the two principal assets (both EUAs and CERs) included in the EU-ETS. We extend the *traditional* PIN model in order to adapt it to the particularities of the European Emissions Market. The adapted structural model allows us to extract information from unobservable microstructure parameters by analyzing the trading activity of both assets.

[28] We reject the equality of variances (Brown-Forsythe test) between the nearest maturity rollover series and the second nearest maturity series, at the 5% level, but we cannot reject the equality of variances in the other two cases.

[29] We reject the equality of means (t-test) and medians (Kruskal-Wallis test), at the 5% level, in all cases.

[30] In order to obtain robustness, we repeated the entire analysis with the spot contracts, obtaining higher spreads for both EUAs and CERs. These results are available upon request.

Specifically, we presented the informed trading behavior, identified seasonality patterns and analyzed the derived theoretical opening spreads.

Our database is composed of all the available "screen" trades, for all EUA and CER December futures contracts, registered on the ICE ECX market (London) from March 2008 to December 2011. This platform represents the main reference of the futures market for both assets.

We observe a seasonality pattern in the estimated PIN. Higher PIN levels for EUAs are observed during December, January, February and March, exhibiting a positive trend during these four months, and suggesting an increase in informed trading activity before the publication of the verified emissions reports. On the other hand, CERs exhibit higher PIN levels as we approach the end of the year, consistent with the idea that traders acquire CERs when they have the certainty of how many they will need. We identify the maximum probability of occurrence of an informational event (α) in April, again consistent with the verified emissions calendar, as all the verified emissions reports will be made public between April 1^{st} and May 15^{th}.

The PIN history analysis presents a negative trend of α, in accordance with a decrease in the probability of occurrence of informational events over time. Although the slope is not very steep, this fact reveals an increase in the maturity of the carbon market. In a parallel way, the probability that the informational event is negative (δ) shows a positive trend over time, with the slope being steeper during the last quarter of 2010 and 2011, in accordance with both EUA and CER price decreases. We observe that the EUA PIN stays stable on average during the sample period, while the CER PIN rises in accordance with the trading activity, which ratifies its increasing importance. We corroborate the leadership of the nearest December contract, although we observe an increasing importance of those contracts with further maturities. Nevertheless, further maturity contracts still exhibit higher PIN values than the December front contract, for both EUAs and CERs.

The theoretical opening spread in the case of the EUA (CER) shows a decreasing (stable) trend until the fourth quarter of 2010, when the spread starts increasing, probably because of the financial crisis, and the subsequent fall of EUA (CER) prices. We also report a remarkable peak on the EUAs opening spread in the first quarter of 2009. A peak is also detected in the furthest CER December rollover series. In general, the theoretical opening spread presents lower values for the nearest maturity contracts and on CER contracts, because of their lower PIN levels.

The analysis of the whole picture illustrates the increasing importance of CERs in the European carbon market, reason why they should be considered by traders, researchers and regulators in their portfolio analyses, research projects and regulator decisions, respectively. The inefficiencies detected around the verified emissions calendar, where the emitter companies can take advantage of their private information, highlights the need for regulators to take actions to avoid this practice, provide transparency and guarantee the protection of all the external traders, which will help to increase market liquidity.

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Table I. Compliance timeline

This table contains the essential deadlines of the compliance timeline, which each company should attend to every year. "Date" refers to the specific day or month of the requirement. "Compliance Requirements" refers to the event that must be attended to.

Date	Compliance Requirements
January 1st	Compliance year begins.
February 28th	EUAs for the present year must be issued by this deadline.
March 31th	Deadline for submitting the verified emissions report for the previous year and entering the emissions into the Registry.
April 30th	The involved companies must surrender the EUAs for the previous compliance year.
May 15th	The European Commission publishes the verified emissions by this date.
June 30th	Those companies which fulfill certain conditions are obligated to submit their improvement reports to their regulator.
Between June and August	Companies should commence their verification process for the present year.
By December	Companies should start preparing the annual emissions report for the present year.
December 31st	Compliance year ends.

Table II. Sample data: General statistics

This table contains sample descriptive statistics per contract. We display exclusively statistics for screen trades. Panel A (B) provides the time stamp for the first and the last trades, several trading activity and trade-size statistics, the number of trading days, and the aggregated number of trades and volume for each EUA (CER) futures contract used in the study. During the work we employed data from 7 different December contracts, specifically those with maturities between December 2008 and December 2014. "Buy" ("Sell") refers exclusively to initiated buy (sell) trades. One lot equals 1,000 tonnes of CO_2 equivalent gas.

Panel A: EUA Futures Contracts	Delivery						
	December 2008	December 2009	December 2010	December 2011	December 2012	December 2013	December 2014
First trade: Day	03/14/08	03/14/08	03/14/08	03/14/08	03/14/08	01/21/11	02/02/11
First trade: Time	7:01:17 AM	7:21:31 AM	9:20:20 AM	8:04:59 AM	9:35:17 AM	9:36:00 AM	12:51:00 PM
Last trade: Day	12/15/08	12/14/09	12/20/10	12/19/11	12/30/11	12/30/11	12/30/11
Last trade: Time	4:41:34 PM	4:59:11 PM	4:59:00 PM	4:57:42 PM	4:59:42 PM	4:26:04 PM	1:19:33 PM
Maximum trade size (Buy)	200	280	500	518	976	900	250
Average trade size (Buy)	4.53	4.65	7.58	8.09	9.68	9.44	7.51
Median trade size (Buy)	2.0	1.0	3.0	2.0	3.0	2.0	1.0
Minimum trade size (Buy)	1	1	1	1	1	1	1
Maximum trade size (Sell)	200	250	976	679	750	995	500
Average trade size (Sell)	4.45	5.05	7.54	8.41	9.00	8.05	8.86
Median trade size (Sell)	2.0	1.0	2.0	3.0	3.0	2.0	1.0
Minimum trade size (Sell)	1	1	1	1	1	1	1
Maximum number of trades in a day (Buy)	838	1,327	1,869	1,847	1,495	515	123
Average number of trades per day (Buy)	307.04	287.03	207.78	182.48	72.00	60.05	13.67
Median number of trades per day (Buy)	298.0	227.5	60.0	40.5	37.0	44.0	6.0
Minimum number of trades in a day (Buy)	45	0	0	0	0	1	0
Maximum number of trades in a day (Sell)	895	1,061	1,936	1,697	1,305	552	138
Average number of trades per day (Sell)	288.80	287.98	201.95	175.31	80.00	92.09	20.18
Median number of trades per day (Sell)	271.0	255.5	57.0	37.0	37.0	75.0	11.0
Minimum number of trades in a day (Sell)	34	0	0	0	0	2	0
Number of trading days	194	448	706	958	965	239	239
Number of trades (Buy)	59,566	128,591	146,694	174,814	69,480	14,351	3,268
Number of trades (Sell)	56,027	129,017	142,578	167,945	77,202	22,010	4,823
Volume in lots (Buy)	269,572	598,544	1,112,282	1,414,710	672,774	135,473	24,537
Volume in lots (Sell)	249,584	651,171	1,075,577	1,412,449	694,724	177,228	42,724

Table II. Sample data: General statistics

Panel B: CER Futures Contracts	Delivery						
	December 2008	December 2009	December 2010	December 2011	December 2012	December 2013	December 2014
First trade: Day	03/14/08	03/17/08	03/18/08	03/17/08	03/17/08	01/24/11	03/04/11
First trade: Time	7:00:00 AM	9:02:39 AM	1:15:58 PM	9:14:15 AM	2:25:40 PM	10:52:20 AM	4:43:35 PM
Last trade: Day	12/15/08	12/14/09	12/20/10	12/19/11	12/30/11	12/30/11	12/20/11
Last trade: Time	4:59:54 PM	4:56:54 PM	4:59:17 PM	4:59:28 PM	2:17:15 PM	2:17:15 PM	11:32:45 AM
Maximum trade size (Buy)	100	100	250	250	500	200	50
Average trade size (Buy)	8.18	9.19	10.29	8.08	8.51	5.59	4.97
Median trade size (Buy)	5.0	6.0	8.0	4.0	4.0	1.0	1.0
Minimum trade size (Buy)	1	1	1	1	1	1	1
Maximum trade size (Sell)	95	200	250	500	300	250	29
Average trade size (Sell)	8.39	8.89	9.63	8.38	8.83	5.00	7.13
Median trade size (Sell)	9.0	7.0	5.0	5.0	4.0	1.0	1.0
Minimum trade size (Sell)	1	1	1	1	1	1	1
Maximum number of trades in a day (Buy)	120	79	174	275	387	181	40
Average number of trades per day (Buy)	17.31	12.31	13.68	18.85	17.98	11.47	0.94
Median number of trades per day (Buy)	11.0	8.0	6.5	6.0	6.0	2.0	0.0
Minimum number of trades in a day (Buy)	0	0	0	0	0	0	0
Maximum number of trades in a day (Sell)	63	123	155	278	469	107	38
Average number of trades per day (Sell)	13.76	13.02	13.66	18.81	19.81	10.46	0.87
Median number of trades per day (Sell)	10.5	9.0	5.5	6.0	7.0	2.0	0.0
Minimum number of trades in a day (Sell)	0	0	0	0	0	0	0
Number of trading days	194	448	706	958	965	239	239
Number of trades (Buy)	3,359	5,516	9,658	18,062	17,355	2,742	225
Number of trades (Sell)	2,669	5,834	9,642	18,021	19,118	2,499	207
Volume in lots (Buy)	27,478	50,697	99,413	145,877	147,609	15,316	1,118
Volume in lots (Sell)	22,406	51,864	92,866	150,998	168,826	12,490	1,476

Table III. Rollovers

This table contains the rollover dates and the contracts included in all three rollover series considered in the study for each asset (EUAs and CERs). Through the last day criterion, we generate three rollover series for each asset, one with the nearest maturity contracts, another with the second nearest maturity contracts, and finally, a third one with the third nearest maturity contracts. According to the elected method, we switch from one contract to the following on the last trading day. "Date" contains the starting ("Start") and ending ("End") dates for the subsamples included in each rollover series. "Dec T" refers to the rollover series composed with the nearest maturity contracts. "Dec T+1" refers to the rollover series composed with the second nearest maturity contracts. "Dec T+2" refers to the rollover series composed with the third nearest maturity contracts. In the table "Dec" refers to the December futures series, and the following number to the year of the delivery, which goes from 2008 ("08") to 2014 ("14").

Date		December Futures Contracts		
Start	End	Dec T	Dec T+1	Dec T+2
3/14/08	12/15/08	Dec08	Dec09	Dec10
12/16/08	12/14/09	Dec09	Dec10	Dec11
12/15/09	12/20/10	Dec10	Dec11	Dec12
12/21/10	12/19/11	Dec11	Dec12	Dec13
12/20/11	12/31/11	Dec12	Dec13	Dec14

Figure 1. Probability tree of the trading model (Traditional Model)

This figure presents the probabilities associated with the events and outcomes of the trading model proposed in Easley, Kiefer and O'Hara (1996, 1997), Easley, Kiefer, O'Hara and Paperman (1996) and Easley, Hvidkjaer and O'Hara (2002). At the left of the dotted line we find the events that take place once a day before the beginning of trading. Informational events occur with probability α, and if they occur, the information is bad (good) with probability δ (1-δ). At the right of the dotted line are the events that take place during the trading day. ε_B (ε_S) represents the rate at which uninformed buy (sell) orders are executed and μ is the arrival rate of informed traders.

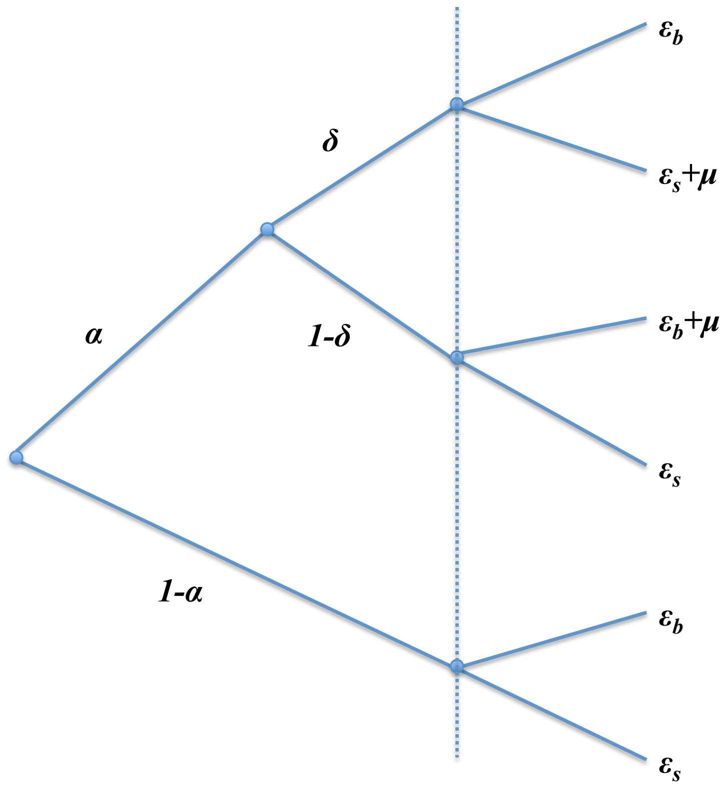


Figure 2. Probability tree of the trading model (Carbon Market Model)

This figure presents the probabilities associated with the events and outcomes of the trading model proposed for the carbon market. At the left of the dotted line we find the events that take place once a day before the beginning of trading. Informational events occur with probability α, and if they occur, the information is bad (good) with probability δ (1-δ). At the right of the dotted line are the events that take place during the trading day. ε_B (ε_S) represents the rate at which uninformed buy (sell) orders are executed, μ is the arrival rate of informed traders, β (1- β) is the fraction of informed traders which trade CER (EUA) contracts, τ (1-τ) is the fraction of uninformed traders which buy CER (EUA) contracts and φ (1-φ) is the fraction of uninformed traders which sell CER (EUA) contracts.

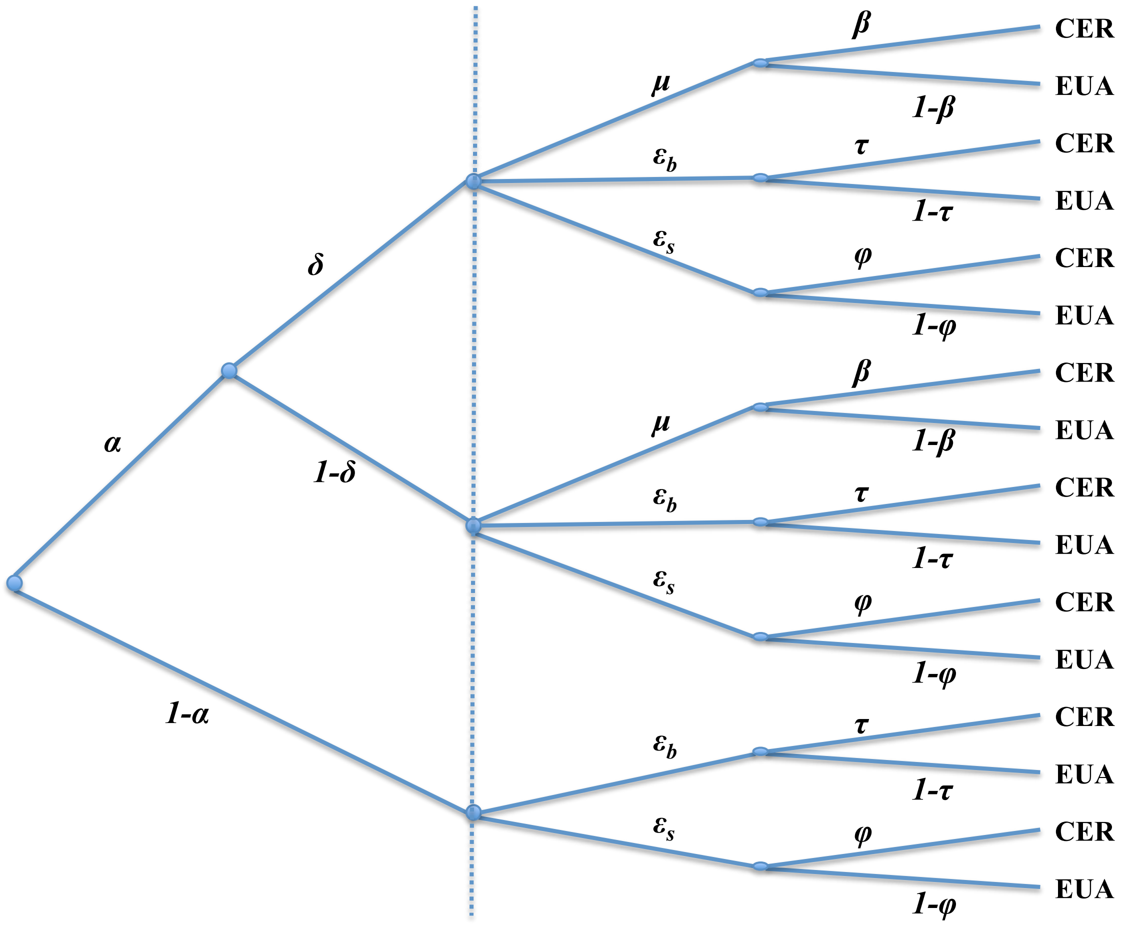
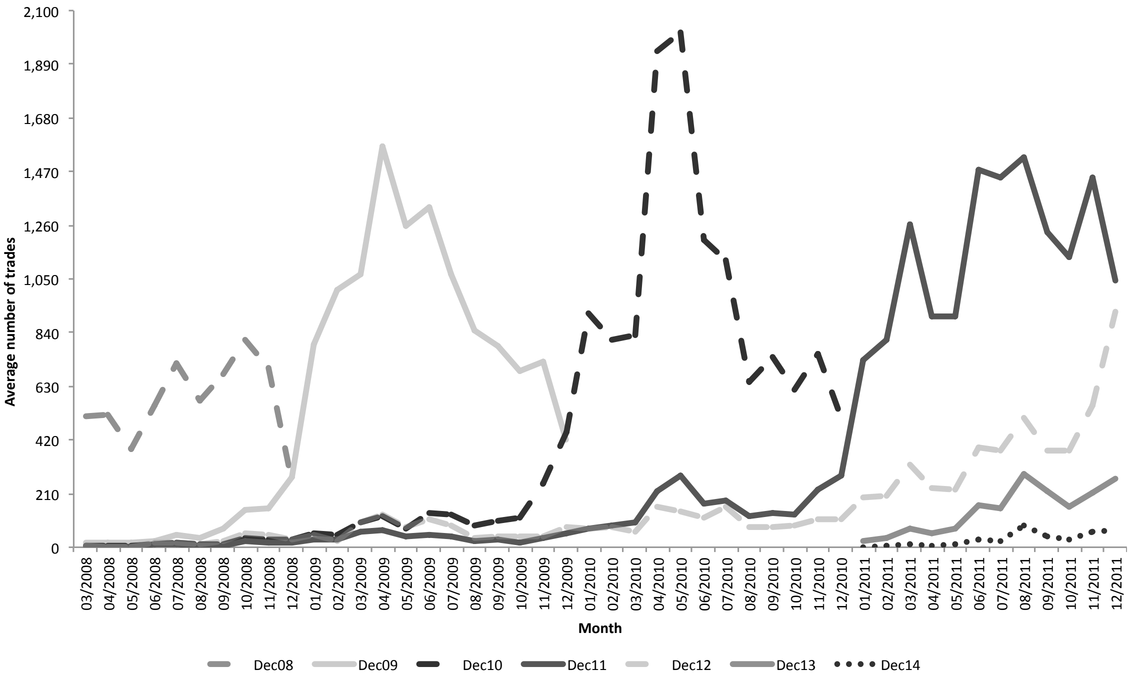
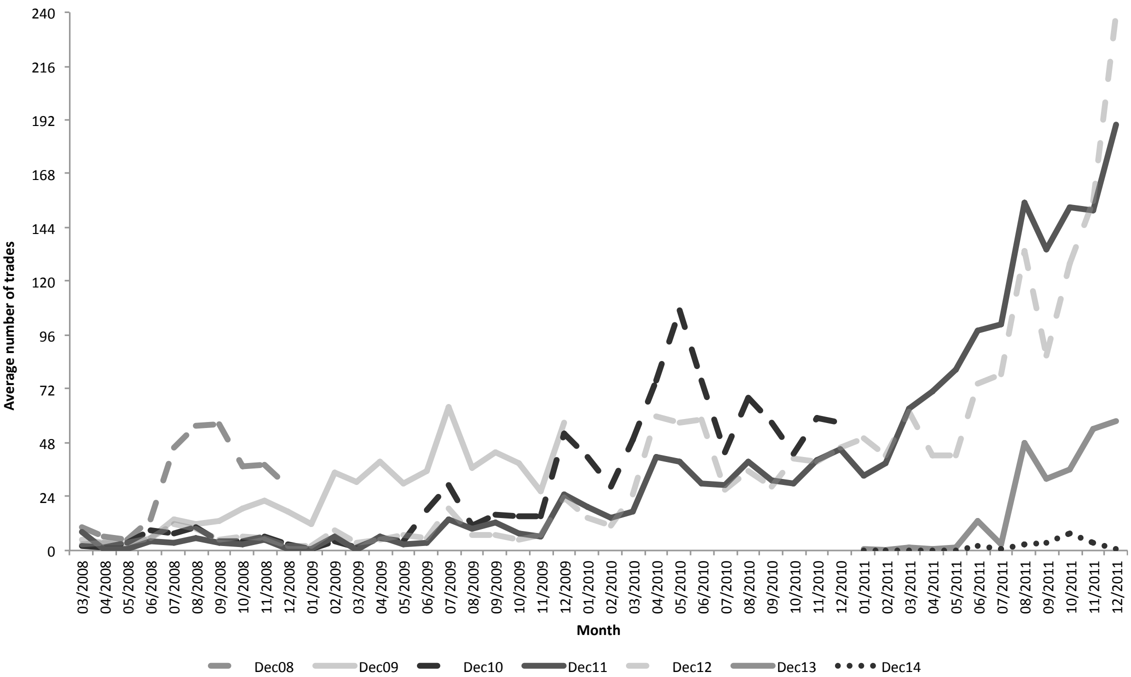


Figure 3. Average number of trades per futures contract

In figure 3a (3b) we plot the monthly average number of trades per day, for each Phase II EUA (CER) Futures Contract with delivery in December, employed in our empirical analysis. Specifically, we plot all December ("Dec") futures contracts between 2008 ("08") and 2014 ("14") for the period from March 2008 to December 2011.



(a) EUA futures contracts



(b) CER futures contracts

Figure 4. Seasonality

This figure presents the estimated carbon market PINs and the α parameter, per month. In order to compute the estimation, we took into account all the available front contracts for each specific year. In the joint-estimation, we fixed α and δ, leaving free the rest of the variables (β, τ, φ, μ, ε_B and ε_S) along the different series. "PIN EUAs" refers to the *total* PIN for the EUA contracts. "PIN CERs" refers to the *total* PIN for the CER contracts. "α" refers to the probability of occurrence of an informational event.

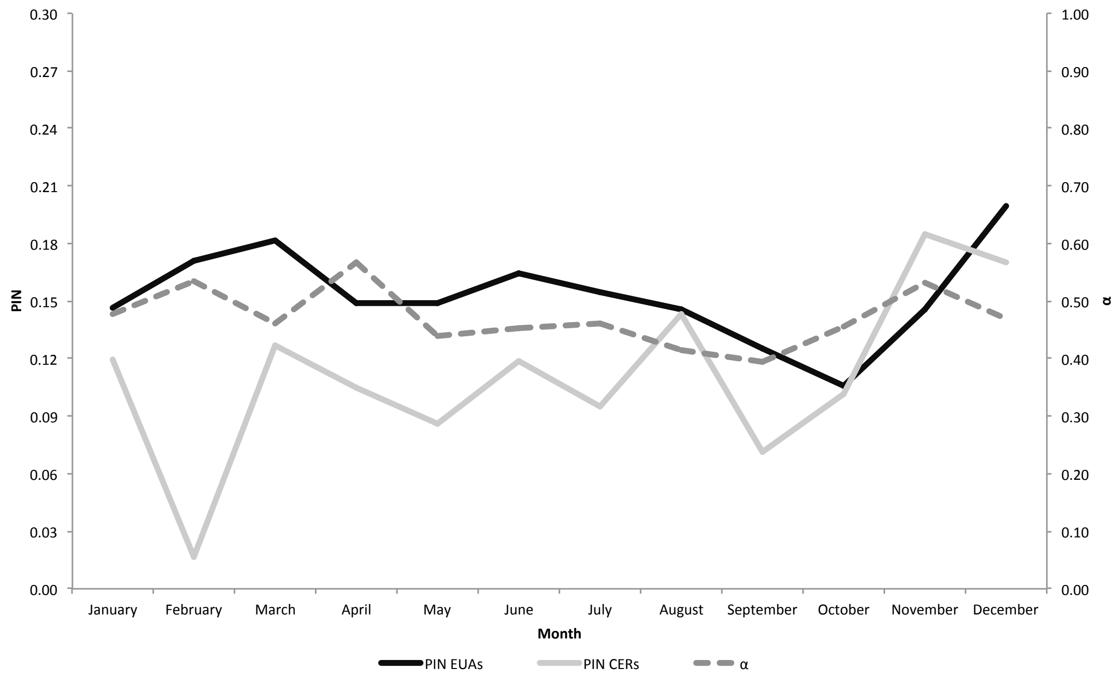
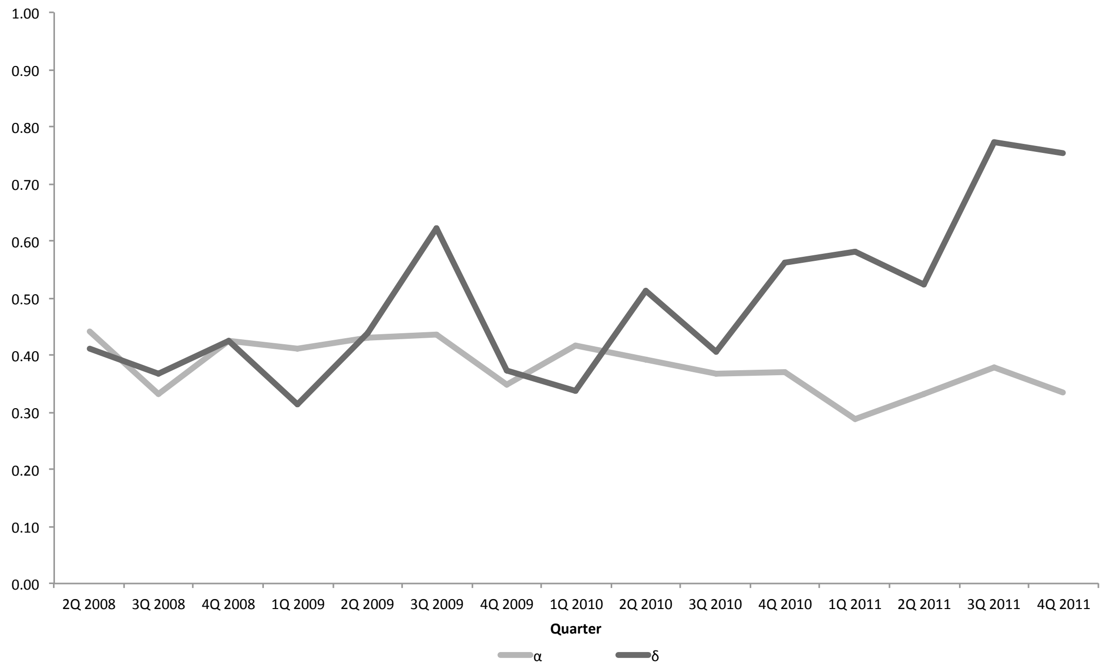


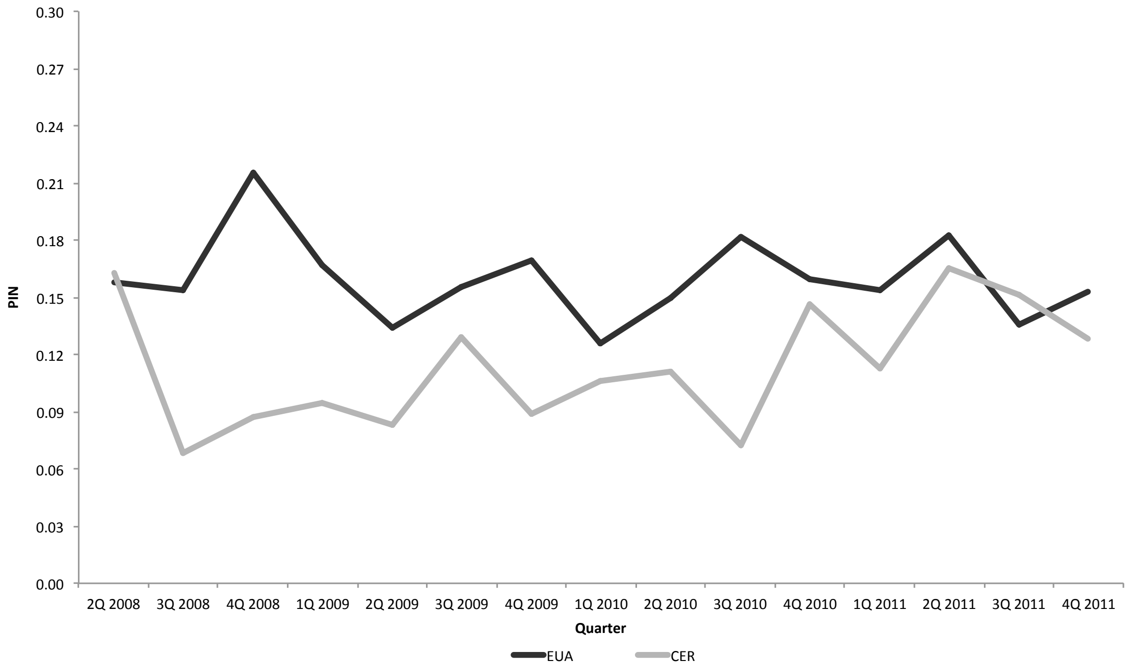
Figure 5. PIN behavior futures contract

The figures plot the estimated PIN variables per quarter (3 months), from the second quarter of 2008 to the last quarter of 2011. The PIN estimations have been computed using the three nearest December rollover series, fixing α and δ, and leaving free the rest of the variables (β, τ, φ, μ, ε_B and ε_S), along the different rollover series. Figure 5a plots the evolution of the α and δ estimated parameters. Figure 5b plots the *aggregated* PINs of the carbon market, where "EUA" refers to the EUA's *aggregated* PIN and "CER" to the CER's *aggregated* PIN. Figure 5c plots the different PINs per contract, where "Dec T" refers to the front December rollover series, "Dec T+1" refers to the second nearest December rollover series, and "Dec T+2" refers to the third nearest December rollover series. Figure 5d plots β, τ and φ per rollover series, where "Dec T" refers to the front December rollover series, "Dec T+1" refers to the second nearest December rollover series, and "Dec T+2" refers to the third nearest December rollover series. Figure 5e plots μ, ε_b and ε_s per rollover series, where "Dec T" refers to the front December rollover series, "Dec T+1" refers to the second nearest December rollover series, and "Dec T+2" refers to the third nearest December rollover series. Figure 5f plots the percentage of informed trading for each rollover series, where "Dec T" refers to the front December rollover series, "Dec T+1" refers to the second nearest December rollover series, and "Dec T+2" refers to the third nearest December rollover series.

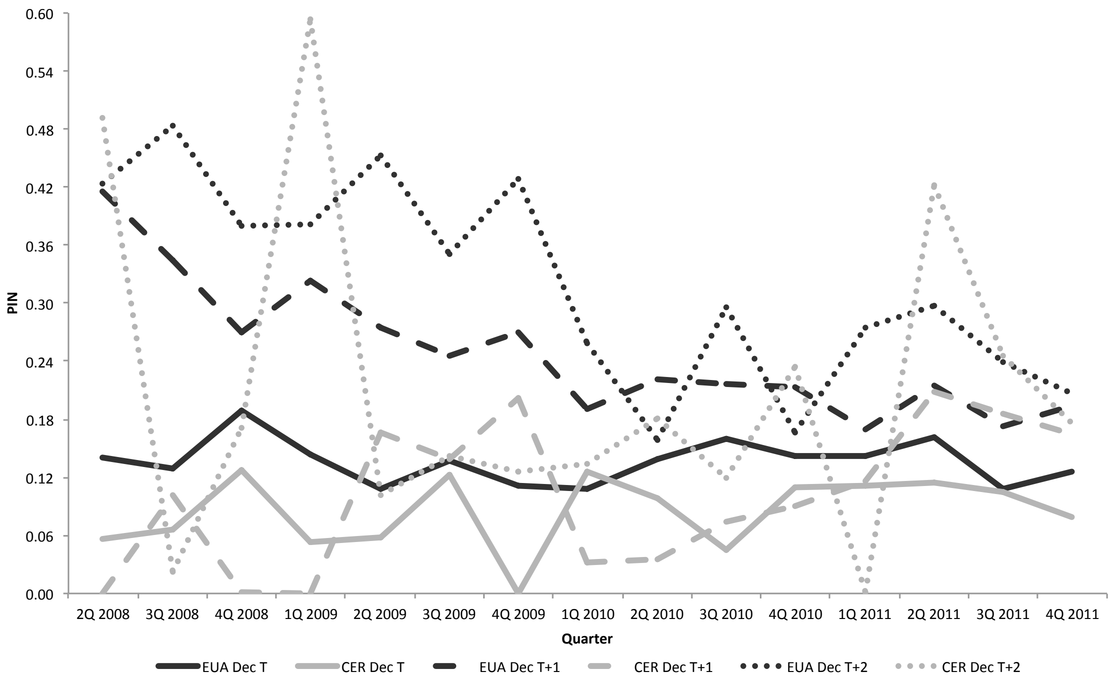


(a) Daily variables

Figure 5. PIN behavior futures contract (continued)

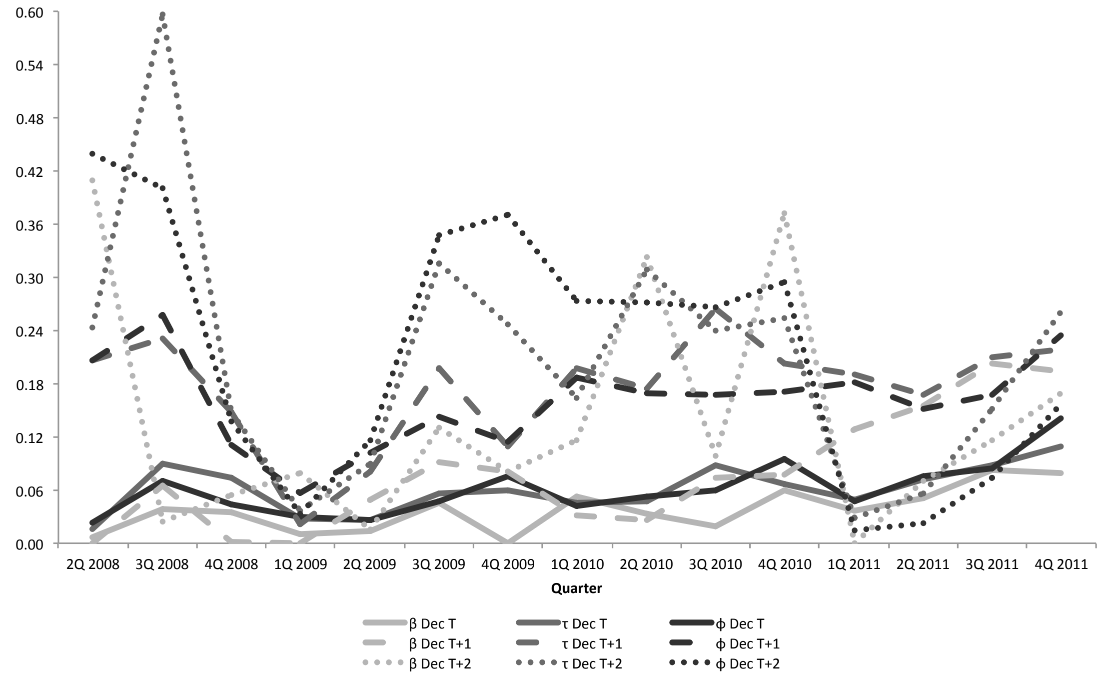


(b) *Aggregated* PINs

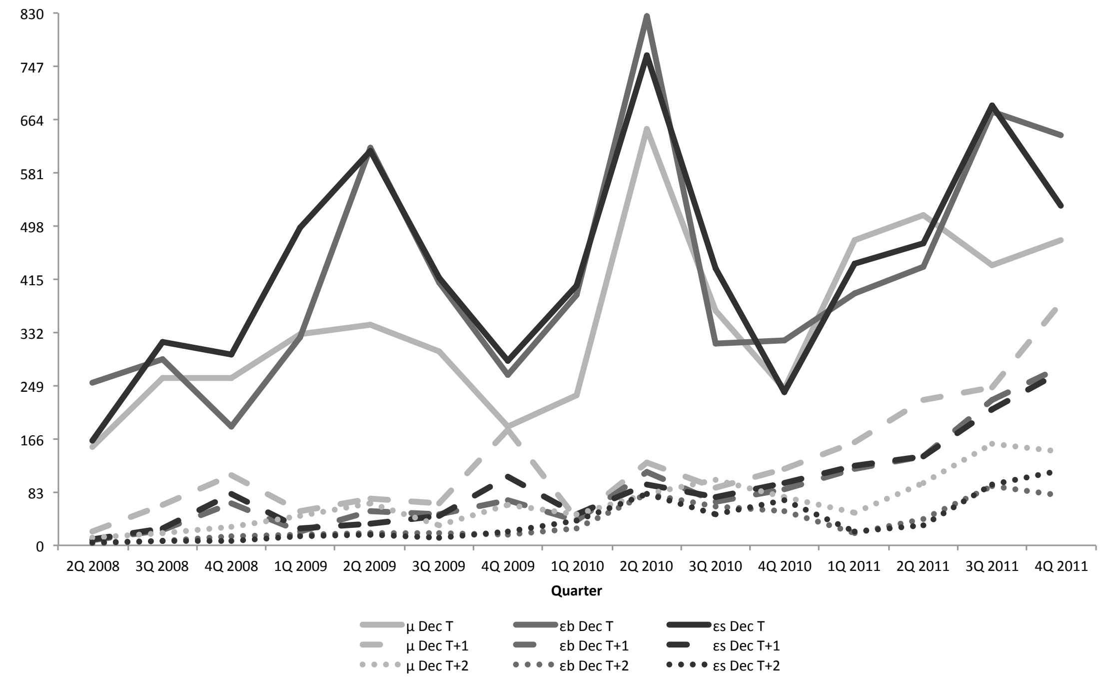


(c) PIN per rollover series

Figure 5. PIN behavior futures contract (continued)

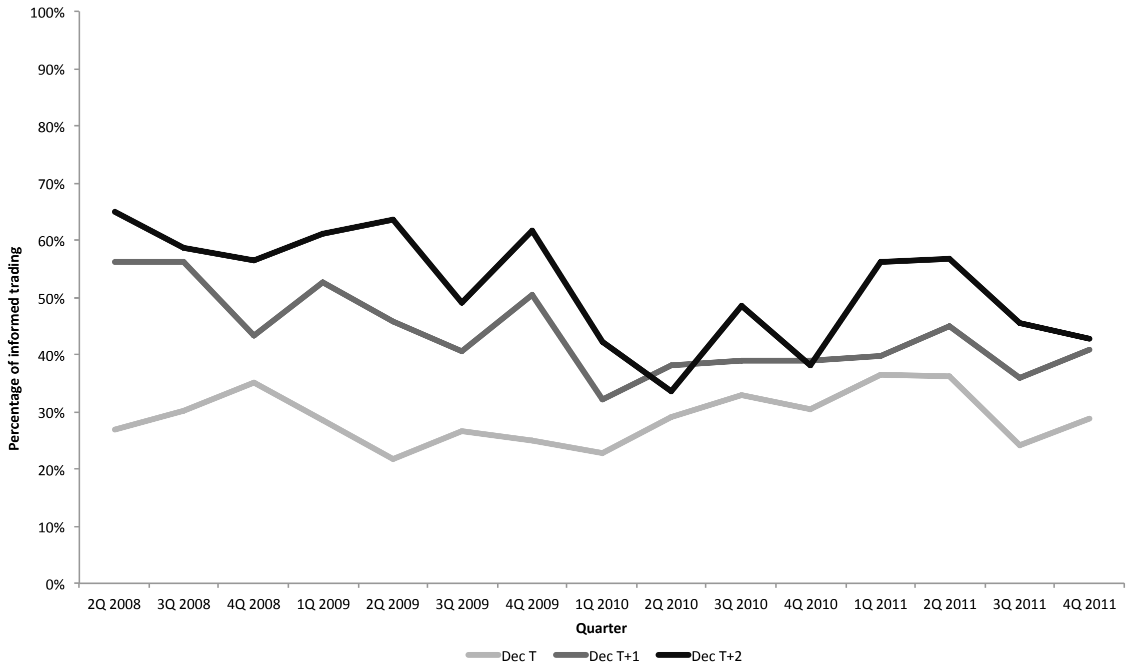


(d) β, τ and φ per rollover series



(e) μ, ε_b and ε_s per rollover series

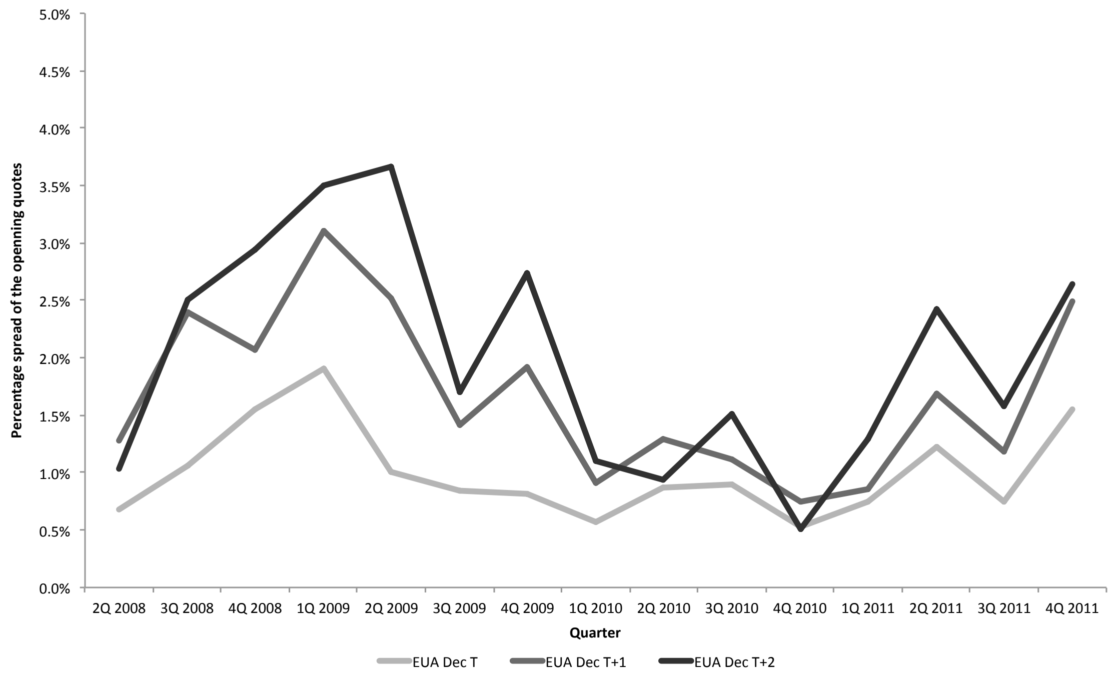
Figure 5. PIN behavior futures contract (continued)



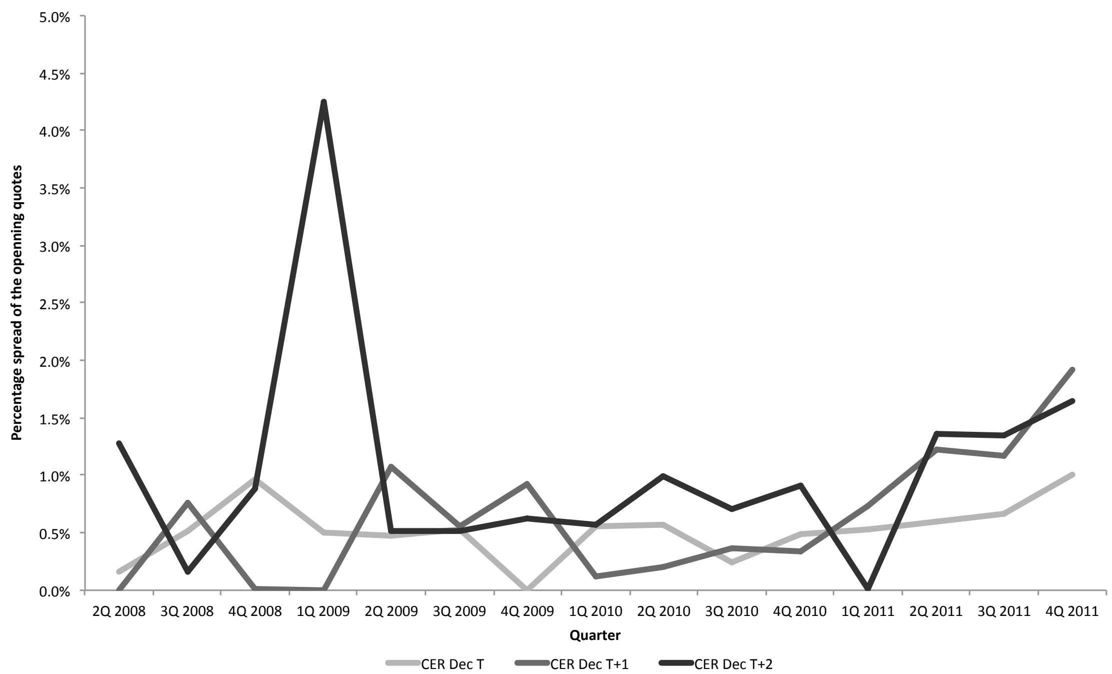
(f) Percentage of informed trading per rollover series

Figure 6. Theoretical opening spreads

In figure 6a (6b) we plot the evolution of the theoretical percentage spreads of the opening quotes for the three nearest EUA (CER) December rollover series. "EUA Dec T" ("CER Dec T") refers to the nearest maturity EUA (CER) December rollover series, "EUA Dec T+1" ("CER Dec T+1") refers to the second nearest maturity EUA (CER) December rollover series, and "EUA Dec T+2" ("CER Dec T+2") refers to the third nearest maturity EUA (CER) December rollover series.



(a) EUA rollover series



(b) CER rollover series

Appendix A. Numerical approaches

Appendix A.1 (A.2) provides several approaches which could be computed to estimate the *traditional* PIN model's (carbon market PIN model's) likelihood function, in order to reduce numerical problems when the number of buys and sells is very large.

Appendix A.1. *Traditional* PIN Model Approaches

$$\exp(-\varepsilon_b)\frac{\varepsilon_b^{B_i}}{B_i!}=\exp\left[-\varepsilon_b+B_i\ln(\varepsilon_b)-\sum_{j=1}^{B_i}\ln(j)\right]$$

$$\exp(-\varepsilon_s)\frac{\varepsilon_s^{S_i}}{S_i!}=\exp\left[-\varepsilon_s+S_i\ln(\varepsilon_s)-\sum_{j=1}^{S_i}\ln(j)\right]$$

$$\exp\left[-(\varepsilon_b+\mu)\right]\frac{(\varepsilon_b+\mu)^{B_i}}{B_i!}=\exp\left[-(\varepsilon_b+\mu)+B_i\ln(\varepsilon_b+\mu)-\sum_{j=1}^{B_i}\ln(j)\right]$$

$$\exp\left[-(\varepsilon_s+\mu)\right]\frac{(\varepsilon_s+\mu)^{S_i}}{S_i!}=\exp\left[-(\varepsilon_s+\mu)+S_i\ln(\varepsilon_s+\mu)-\sum_{j=1}^{S_i}\ln(j)\right]$$

Appendix A.2. Carbon Market PIN Model Approaches

$$\exp\left[-(1-\tau)\varepsilon_b\right]\frac{\left[(1-\tau)\varepsilon_b\right]^{B_i^{EUA}}}{B_i^{EUA}!}=\exp\left[-(1-\tau)\varepsilon_b+B_i^{EUA}\ln\left[(1-\tau)\varepsilon_b\right]-\sum_{j=1}^{B_i^{EUA}}\ln(j)\right]$$

$$\exp\left[-\left((1-\varphi)\varepsilon_s+(1-\beta)\mu\right)\right]\frac{\left[(1-\varphi)\varepsilon_s+(1-\beta)\mu\right]^{S_i^{EUA}}}{S_i^{EUA}!}=\exp\left[-\left((1-\varphi)\varepsilon_s+(1-\beta)\mu\right)+S_i^{EUA}\ln\left[(1-\varphi)\varepsilon_s+(1-\beta)\mu\right]-\sum_{j=1}^{S_i^{EUA}}\ln(j)\right]$$

$$\exp(-\tau\varepsilon_b)\frac{(\tau\varepsilon_b)^{B_i^{CER}}}{B_i^{CER}!}=\exp\left[-\tau\varepsilon_b+B_i^{CER}\ln(\tau\varepsilon_b)-\sum_{j=1}^{B_i^{CER}}\ln(j)\right]$$

$$\exp\left[-(\varphi\varepsilon_s+\beta\mu)\right]\frac{(\varphi\varepsilon_s+\beta\mu)^{S_i^{CER}}}{S_i^{CER}!}=\exp\left[-(\varphi\varepsilon_s+\beta\mu)+S_i^{CER}\ln(\varphi\varepsilon_s+\beta\mu)-\sum_{j=1}^{S_i^{CER}}\ln(j)\right]$$

$$\exp\left[-\left((1-\tau)\varepsilon_b+(1-\beta)\mu\right)\right]\frac{\left[(1-\tau)\varepsilon_b+(1-\beta)\mu\right]^{B_i^{EUA}}}{B_i^{EUA}!}=\exp\left[-\left((1-\tau)\varepsilon_b+(1-\beta)\mu\right)+B_i^{EUA}\ln\left[(1-\tau)\varepsilon_b+(1-\beta)\mu\right]-\sum_{j=1}^{B_i^{EUA}}\ln(j)\right]$$

$$\exp\left[-(1-\varphi)\varepsilon_s\right]\frac{\left[(1-\varphi)\varepsilon_s\right]^{S_i^{EUA}}}{S_i^{EUA}!}=\exp\left[-(1-\varphi)\varepsilon_s+S_i^{EUA}\ln\left[(1-\varphi)\varepsilon_s\right]-\sum_{j=1}^{S_i^{EUA}}\ln(j)\right]$$

$$\exp\left[-(\tau\varepsilon_b+\beta\mu)\right]\frac{(\tau\varepsilon_b+\beta\mu)^{B_i^{CER}}}{B_i^{CER}!}=\exp\left[-(\tau\varepsilon_b+\beta\mu)+B_i^{CER}\ln(\tau\varepsilon_b+\beta\mu)-\sum_{j=1}^{B_i^{CER}}\ln(j)\right]$$

$$\exp(-\varphi\varepsilon_s)\frac{(\varphi\varepsilon_s)^{S_i^{CER}}}{S_i^{CER}!}=\exp\left[-\varphi\varepsilon_s+S_i^{CER}\ln(\varphi\varepsilon_s)-\sum_{j=1}^{S_i^{CER}}\ln(j)\right]$$

Conclusions

1. Conclusions

In this PhD dissertation thesis we have analyzed in depth the European carbon market, focusing on the two most-traded emissions carbon credits: European Union Allowances (EUAs) and Certified Emission Reductions (CERs).

1.1. Major findings

I. The statistical properties of EUA returns suggest we are facing a new type of asset.

II. We suggest that the simplest rollover methodology, which consists in rolling over on the last trading day, should be employed in empirical studies on both EUAs and CERs.

III. The quality of EUA prices has been dramatically affected by the market collapse at the end of Phase I and the posterior financial crisis, and by the end of 2010, the quality of prices was close to, though still below, the levels seen in early 2006.

IV. We report regular and significant increases in information-motivated trading between December and March of each year for EUAs, and at the end of each year for CERs.

1.2. Minor comments

I. We find evidence of intermittency, aggregational gaussianity, short-term predictability, the Taylor effect, volatility clustering, asymmetric volatility, positive relationships between volatility and (a) volume and (b) changes in open interest, temporal dependencies (which implies modeling with ARMA-GARCH structures), negative asymmetry, positive correlation with stock indexes, higher volatility levels during the trading session, existence of inflation hedges and negative correlation with bonds.

II. Liquidity analysis with different rollover criteria show that the methodologies based on the open interest variable, are not suitable to be used in liquidity studies.

III. The quality of the ECX market has not markedly changed from futures contracts with maturities in Phase I to those in Phase II, even though Phase II shows higher trading intensity, lower immediacy, lower risk of information asymmetries or adverse selection costs, and lower levels of both price return volatility and friction-related volatility than Phase I (before the market collapse), friction-related volatility contribution to total volatility has been above ordinary Phase I levels.

IV. We corroborate the price leadership of the nearest December contract, although we observe an increasing importance of those contracts with more distant and we illustrate the increasing importance of CERs in the European carbon market.

2. Further research

The results obtained in this dissertation thesis have shed light on some important questions which remained unanswered in the European carbon market literature. Nevertheless, in my opinion, more research should be done related to the microstructure and the efficiency of the market.

A key component of future research could be to develop statistical methods to detect price manipulation from microstructure data and demonstrate their effectiveness in carbon markets. The detection of price manipulation is of great importance nowadays; although price manipulation is illegal, many studies show that it is possible to manipulate the market. Sometimes the authorities manage to detect these activities, but many remain in the shadows and thus it makes sense to develop new models whose objective is to help detect these practices. To do so, we could extend the model proposed by Allen and Gale (1992) by adapting it to the particularities of the European carbon market. Allen and Gale (1992) propose a rational expectations model with asymmetric information, where all agents maximize their expected utility, in a finite horizon framework. In this economy the "manipulator" simply buys and sells a stock in one unique market, where firm manipulation or false rumors are not allowed. There are two types of investors, passive investors (risk averse) and large investors (risk neutral), where these last ones split in two subcategories, informed traders and manipulators (uninformed). Investors cannot determinate whether if a large trade is work of an informed investor or a manipulator. Two assets coexist in the market, a stock and cash. The first asset will pay a high value or a low value at the end of the last period, with a given probability. The second asset is riskless and zero yield. In this framework, an informed event can occur with a certain probability and this can be positive or negative. The trading process takes place in three dates, where initially the investors hold all the stocks. In the first step, the informed trader enters into the market only if he anticipates an announcement, while manipulators only enter if no news is expected. If an informed event occurs, bad news are revealed before than good news. Finally, all traders maximize the expected utility of their final wealth. The results show that manipulation is possible without actions that alter the true value of the firm or spreading false information, moreover, when investors' beliefs are that the large trader is informed, manipulation is more profitable.

After proving the existence of information asymmetries and informed trading in the European carbon market, the detection of price manipulation practices, would analyze other type of inefficiency. Efficiency is important because the more efficient the carbon market is, the better it will fulfill its real objective, that of providing a platform from which allowance surpluses and needs can be matched.

A second research paper could apply the use and/or extension of the methodology proposed by Easley, López de Prado and O'Hara (2012) to the particularities of the carbon market in order to verify how informed trading behaves over short periods close to specific events occurring in the European carbon market, such as the announcements of the National Allocation Plans (NAPs) for Phase II, and other relevant news concerning Phase III. Easley, López de Prado and O'Hara (2012) take into account the traded volume and the volume-time, in order to detect flow toxicity in a high frequency framework. The sequential traded model assumes that trades are informative about the future value of the asset, and they have varying importance for the magnitude of future price movements. The more relevant a piece of news is, the more volume it attracts. The methodology proposes to group the volume in buckets of equal magnitude, where through the sign of the orders included in each bucket, we are able to identify the trade imbalance and derive a measure of flow toxicity denominated VPIN or "volume-synchronized probability of informed trading".

Additionally, the analysis made in Chapters I and III could be extended to CER futures contracts, comparing the results with the ones obtained for EUAs, and applying other statistical properties and methodologies to both assets, while in Chapter II, a complete analysis of Phase III contracts for both EUAs and CERs, could be very useful for future researchers in this market.

References

Allen, F., Gale, D., 1992. Stock-Price Manipulation, *Review of Financial Studies* 5, 503-529.

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Resumen

1. Introducción

Dado que ninguno de los cuatro capítulos están escritos en alguna de las dos lenguas oficiales de la Universitat de València, y cumpliendo con su normativa, a continuación procederé a resumir en castellano los 4 capítulos que forman la tesis doctoral.[1]

La presente tesis tiene como objetivo el estudio de algunos aspectos de los precios y transacciones llevadas a cabo en el mercado de los derechos de emisión sobre CO_2 en Europa. El Capítulo I se dedica al estudio de las propiedades estadísticas presentes en los rendimientos de los precios de los derechos de emisión sobre CO_2, con el objetivo de comprobar si dicho activo se comporta como un activo financiero, una mercadería u otro tipo de activo. En el Capitulo II se analizan las diferentes formas de enlazar series de contratos de futuro sobre los derechos de emisión, con el objetivo de verificar si existen diferencias significativas en los resultados obtenidos, tras la elección de un método concreto. El Capítulo III estudia el impacto que el colapso en precios de finales de 2006 y la posterior irrupción de la crisis financiara tuvieron sobre la calidad de precios del mercado europeo de CO_2, inversamente relacionada con las distorsiones que sufren las serie de precios, así como la evolución temporal de las fricciones del mercado de futuros sobre derechos de emisión. Por último, el Capítulo IV se centra en la detección de asimetrías de información en el mercado europeo de derechos de emisión sobre CO_2.

[1] El presente resumen se ha realizado en cumplimiento del Artículo 7.2 de la Normativa reguladora de los procedimientos de elaboración, autorización, nombramiento del Tribunal, defensa y evaluación de las tesis doctorales de la Universitat de València, aprobada en Consejo de Gobierno el 29 de noviembre de 2011.

1.1. Capítulo I: ¿Es el EUA una nueva clase de activo?

El comienzo de la negociación de cualquier activo requiere del conocimiento de las propiedades estadísticas derivadas de sus rendimientos en precios, para su uso ya sea con fines de cobertura o con fines especulativos. En el presente capítulo se estudian los hechos estilizados de los rendimientos derivados de los precios de los derechos de emisión sobre CO_2 (*European Union Allowances,* EUAs).

Tras la ratificación del Protocolo de Kioto y con el objetivo de cumplir con los compromisos alcanzados en el mismo, la Unión Europea decidió que una gran parte de dicha reducción debería ser asumida por las compañías de los sectores más contaminantes. Desde el 2005, las compañías incluidas en la Directiva 2003/87/CE reciben cada año derechos de emisión con el objetivo de cubrir sus emisiones de CO_2 o gas equivalente a la atmósfera. Dichos derechos pueden ser negociados en diversos mercados organizados en Europa. En cualquier caso, al final de cada año, dichas empresas tienen que entregar suficientes derechos para cubrir sus emisiones.

Mediante el estudio de las propiedades estadísticas de los rendimientos de los precios, se puede determinar desde un punto de vista estadístico, si el activo con el que tratamos se comporta como una mercadería, un activo financiero u otro tipo de activo. De hecho, los derechos se negocian en mercados organizados desde el año 2005, pero fue en octubre de 2011 cuando la Unión Europea decidió calificarlos como activos financieros.

En este capítulo nos hemos centrado en los activos de la Fase II, puesto que la primera fase fue una fase piloto y de aprendizaje.[2] En concreto, se han utilizado los datos diarios de los futuros cotizados en el ICE ECX con vencimientos en diciembre de

[2] La Fase I comprende el periodo 2005-2007, mientras que la Fase II engloba el periodo 2008-2012.

2008, 2009 y 2010. Señalar que los futuros con vencimiento en el mes de diciembre cotizados en el mercado ICE ECX de Londres, son los activos más líquidos relacionados con el CO_2 existentes hasta la fecha, de ahí que sean los elegidos para el estudio.[3]

Las distintas propiedades que se han estudiado se han integrado en cuatro grupos.[4] El primero es el de las características relacionadas con la distribución estadística de los rendimientos. En general, se ha analizado la normalidad de la distribución de los rendimientos, y en caso de rechazarla, se ha estudiado la presencia de asimetría y de colas pesadas, así como la existencia y persistencia de observaciones extremas. Estos resultados ayudan a determinar si la distribución estadística es gaussiana. En el segundo grupo se han analizado las propiedades relacionadas con la correlación serial, y en particular, la autocorrelación de los rendimientos, la aleatoriedad en la generación de los rendimientos y la prolongación en el tiempo de la autocorrelación de los rendimientos en términos absolutos. En el tercer grupo se han estudiado una serie de características relacionadas con la volatilidad, en concreto, se ha analizado la existencia de agrupamientos en la volatilidad, la asimetría en la respuesta de los rendimientos a *shocks* negativos, la existencia de colas pesadas en la distribución de los residuos derivados de la modelización de los rendimientos, la correlación entre el volumen y la volatilidad, y finalmente, la correlación entre la volatilidad y la variación en el volumen abierto. Por último, el último grupo de propiedades engloba diversas propiedades relacionadas con las mercaderías, entre ellas, la existencia de algún tipo de estacionalidad relacionada con el clima, la correlación con activos de renta fija e índices

[3] La plataforma ICE ECX es una plataforma electrónica que permite la negociación de derechos a lo largo de una sesión abierta a la negociación de forma continua. Es de destacar, que la fluctuación mínima de los precios es de 0,01€ y en el mercado operan creadores de mercado que deben mantener un nivel mínimo tanto de horquilla, como de profundidad.

[4] Muchas de las propiedades estudiadas en este capítulo fueros extraídas de los estudios de Cont (2001) y Gorton y Rouwenhorst (2006).

bursátiles, y la posibilidad de que los derechos sobre CO_2 puedan servir como instrumento de cobertura frente a la inflación.

En general, los resultados muestran un rechazo de la normalidad de la distribución estadística de los rendimientos, la existencia de observaciones extremas, la existencia de rendimientos mensuales gaussianos, autocorrelación en los rendimientos, no aleatoriedad en la generación de los rendimientos, persistencia en la autocorrelación de los rendimientos en términos absolutos, agrupamientos significativos de la volatilidad, correlación negativa entre rendimientos y volatilidad, la existencia de colas pesadas en los residuos tras la modelización de los rendimientos, correlación positiva entre volatilidad y volumen, y entre volatilidad y variación del interés abierto, la ausencia de estacionalidad y la ausencia de mayor volatilidad durante el fin de semana. Paralelamente, y contrario al comportamiento de las mercaderías, hemos encontrado evidencia de asimetría negativa en la distribución de los rendimientos, correlación positiva entre los rendimientos de los EUAs y los rendimientos de los índices bursátiles, y mayor volatilidad en los rendimientos cuando el mercado está abierto. Adicionalmente, y contrario a lo observado en los activos financieros, se ha observado una correlación negativa con activos de renta fija y positiva con la inflación no esperada.

El conjunto de las propiedades analizadas indica que los EUAs no se comportan como los típicos activos financieros o mercaderías, y deberían ser considerados como un nuevo tipo de activo. Dichas conclusiones son de gran importancia para el análisis de carteras, la modelización de la volatilidad, la creación de carteras de cobertura y el análisis de cointegración.

1.2. Capítulo II: Construcción de series largas en EUAs y CERs

Los derivados financieros tienen la particularidad de ser activos con vidas finitas. Los investigadores y los intermediarios financieros a la hora de analizar los distintos activos derivados tienen dos opciones: tomar los activos con una vida limitada o enlazar los diferentes activos con el objetivo de construir la serie más extensa posible. La mayoría de los investigadores se suelen decantar por la segunda opción, por ser aquella en la que obtienen las series más largas, algo necesario en la mayoría de análisis estadísticos y econométricos.

Ma, Mercer y Walker (1992) observan que la distribución de la serie de precios era distinta en función de cómo se enlazaban los distintos contratos de futuro, mientras que Carchano y Pardo (2009) llegan a la conclusión opuesta para los contratos de futuro sobre índices y sugieren que el resultado va a depender del activo subyacente que se analice. El objetivo del segundo capítulo es precisamente el análisis de las distribuciones derivadas de los rendimientos de los dos principales activos del mercado europeo de derechos de emisión sobre CO_2, *European Union Allowances* (EUAs) y *Certified Emission Reductions* (CERs), cuando se enlazan los futuros financieros con distintos métodos.

Para el estudio se han empleado datos diarios y de alta frecuencia, de futuros sobre EUAs y CERs, con vencimiento en el mes de diciembre, para el periodo de tiempo que va desde abril de 2005 hasta diciembre de 2011. Adicionalmente, también se han utilizado los futuros con vencimiento en marzo de 2008, por ser éste el último contrato negociado para la Fase I. Toda la base de datos se obtuvo de la plataforma ICE ECX.

Se han comparado y contrastado las distribuciones de los rendimientos obtenidos a partir de cinco metodologías: el primer criterio especifica que el cambio de un vencimiento al siguiente se realiza el último día de negociación del primero; el segundo criterio dicta el paso de un contrato a otro en el momento en el que el segundo contrato muestra sistemáticamente más volumen negociado que el primero; el tercer criterio establece el salto de un contrato a otro cuando el número de contratos abiertos en el segundo es sistemáticamente mayor que en el primero; el cuarto criterio establece el salto de un contrato a otro con un vencimiento más lejano (no siendo necesario que sea el del segundo vencimiento más cercano), cuando el interés abierto es sistemáticamente mayor en un contrato de vencimiento más lejano; por último, el quinto criterio se basa en el ratio definido por Lucia y Pardo (2010), denominada como R3, y que establece que pasaremos de un vencimiento al siguiente, cuando en el primero observemos sistemáticamente que el número de posiciones abiertas en el contrato, es menor que el de posiciones cerradas.

Los resultados del estudio muestran que no se puede rechazar la igualdad de medias, medianas y varianza, de los rendimientos derivados de las 5 distribuciones generadas. De igual forma, la igualdad en las distribuciones de todas las series tampoco puede ser descartada, por lo que concluimos que el método utilizado al enlazar futuros sobre EUAs de la Fase I y II, y de CERs de la Fase II, no ofrece diferencias significativas entre las distribuciones obtenidas, y por tanto el criterio usado para la construcción de series largas de contratos de futuro sobre derechos de emisión, no influye en los resultados de los estudios.

Muchos investigadores, por la imposibilidad o el elevado coste de obtener datos intradiarios, recurren a datos diarios para realizar diferentes análisis de liquidez. Por este motivo, en este capítulo, se ha comprobado adicionalmente si la elección del método para enlazar contratos afecta de alguna forma a la liquidez que muestran las distintas series generadas. En esta ocasión utilizaremos como variable de estudio el número de transacciones intradiarias, en lugar de los rendimientos. Los resultados muestran que para la Fase I no existen diferencias significativas en medias, medianas y varianzas, así como en su distribución, entre las 5 series generadas. Dicha situación cambia cuando lo que se analiza es la Fase II, tanto para EUAs como para CERs, el análisis muestra que dos criterios expuestos anteriormente, el basado en el volumen y el basado en la medida R3, y que dictan que se enlacen los contratos en base al número de posiciones abiertas, muestran sistemáticamente menos liquidez que el criterio basado en el último día,. Por tanto, dichos criterios no deberían ser utilizados en la realización de un análisis de liquidez.

En resumen, a la vista de la evidencia empírica observada, consideramos que la medida más adecuada para enlazar los distintos contratos de EUAs y CERs es la del último día de negociación, por ser ésta la que requiere menos trabajo para su construcción.

1.3. Capítulo III: La historia de las fricciones del mercado europeo del carbono

La literatura en microestructura de los mercados financieros ha mostrado que en horizontes temporales cortos, los precios observados pueden diferir temporalmente de su “verdadero” valor a causa de las fricciones existentes en el mercado. Dichas fricciones son de gran importancia, porque introducen ruido en el proceso de formación del precio, hacen los precios menos informativos, incrementan los costes de inmediatez y reducen la liquidez del mercado. El objetivo de este capítulo es analizar el efecto que el colapso en precios experimentado en el mercado europeo de derechos de emisión sobre CO_2 al final de la Fase I, y la posterior erupción de la actual crisis financiera, han tenido sobre la importancia de este componente "ruidoso" en los cambios de los precios, y por consiguiente, sobre la calidad de los precios de este mercado.

La base de datos procedente del mercado ICE ECX contiene información para todos los futuros sobre EUAs con vencimiento en diciembre, para el periodo de tiempo comprendido entre abril del 2005 y diciembre del 2010. Con el objetivo de disponer de una única serie representativa para cada una de las fases del plan propuesto para el mercado europeo, se procedió a enlazar los distintos futuros con el criterio del máximo volumen, puesto que se demostró en el Capítulo II que este método no pierde ninguna de las propiedades estadísticas deseadas. Señalar adicionalmente que en el capítulo se han analizado exclusivamente las órdenes "*screen*", o de pantalla, siendo éstas las más comunes y utilizadas en el mercado.

Al no estar disponible el libro de órdenes del mercado, las diferentes metodologías utilizadas en el trabajo se han basado exclusivamente en datos de transacciones. La primera de ellas es la propuesta por Roll (1984). Dicha metodología asume un mercado sin asimetrías de información, donde las fricciones de mercado son debidas a fricciones reales reflejadas en la horquilla de precios. Ofrecemos también dos extensiones de esta metodología. En la primera, se introducen los costes de selección adversa permitiendo la existencia de dos tipos de información, pública y privada. En la segunda extensión, se relaja la hipótesis de ausencia de correlación entre el signo (compra vs venta) de las transacciones. La segunda metodología utilizada es la propuesta por Madhavan, Richardson y Roomans (1997). Dicha metodología permite la existencia de fricciones tanto reales (costes de inventario y operativos) como informativas (costes de selección adversa) en los precios, costes de creación de mercado, autocorrelación en el signo de las transacciones, errores de redondeo, y precios discretos. La tercera y última metodología usada en el capítulo es la propuesta por Hasbrouck (1993), en la que se obtiene una medida inversa de calidad en precios por medio de la estimación de la desviación típica del término transitorio en los cambios de precios.

Los resultados muestran que la mediana de la horquilla de precios (*o spread*) estimada durante la Fase I, tanto para el activo de la Fase I, como el de la Fase II, estuvo alrededor de los 4 céntimos de euro, mientras que en la Fase II se redujo por debajo de los 2 céntimos de euro. Los *spreads* muestran una reducción a lo largo del tiempo. En términos relativos, los resultados no varían en el caso de la Fase II, aunque en la Fase I, sí que observamos un incremento de los *spreads* al final de la Fase I, cuando los precios se encontraban cotizando alrededor de cero. El componente de selección adversa en la horquilla de precios muestra una tendencia negativa para los activos de la Fase I y II, durante la Fase I, y estable, durante la Fase II, tanto en términos relativos, como absolutos. Adicionalmente, la descomposición de la volatilidad reporta mayor importancia a las fricciones reales, que a las fricciones por asimetrías de información.

Centrándonos en Roll (1984), los componentes de la volatilidad, en términos porcentuales, muestran que: (i) en la Fase I la volatilidad eficiente desciende hasta su mínimo durante la segunda mitad de 2007, (ii) durante la Fase II la contribución de la volatilidad eficiente fue menor que en la Fase I y (iii) la volatilidad transitoria fue superior en la Fase II con respecto a la observada en la Fase I. Paralelamente, en la metodología propuesta por Madhavan, Richardson y Roomans (1997), se concluye que: (i) los costes por creación de mercado son estables a lo largo de la historia del mercado;

(ii) las estimaciones de la correlación entre transacciones son consistentes con los supuestos; (iii) la probabilidad de reversión del signo de la transacción es siempre menor a 0,5 en la Fase II, y superior que en la Fase I. Adicionalmente, indicar que los dos periodos anormales detectados en ambas fases fueros de distinta naturaleza. Mientras que el periodo de la Fase I, caracterizado por rumores de exceso de derechos de emisión, tuvo como principal componente las fricciones relacionadas con la selección adversa, el periodo de la Fase II, coincidente con el inicio de la crisis financiera, tiene como principal componente las fricciones reales.

Por último, las tres metodologías estudiadas muestran que la calidad de los precios en la Fase I sufrió un deterioro notable en la segunda mitad de 2007, seguramente como consecuencia del desplome de los precios debido al exceso de derechos de emisión existentes durante la Fase I. En cuanto a la Fase II, se observa también un empeoramiento en la calidad de los precios desde 2006 y hasta el primer trimestre de 2009, posiblemente debido al deterioro sufrido por los EUAs de la Fase I y a la posterior crisis financiera. No obstante, la calidad comenzó a recuperarse a lo largo de la Fase II y en 2010 sus niveles eran próximos a los observados a lo largo de 2006.

En conclusión, la calidad de los precios del ICE ECX no ha variado excesivamente entre la Fase I y la Fase II, a pesar de que en la Fase II observamos mayor intensidad en el número de transacciones, menores costes por operación, menores asimetrías de información, menor volatilidad en los precios y menor volatilidad de las fricciones, la contribución de las fricciones a la volatilidad total ha estado presente en la Fase II por encima de los niveles observados en la Fase I. Nuestros resultados muestran, no obstante, que durante gran parte de la Fase II, la calidad del mercado ha venido recuperándose de forma progresiva del efecto negativo producido por el exceso de oferta de derechos durante la Fase I y por la crisis financiera actual. A finales de 2010, sin embargo, esta recuperación todavía no había concluido.

1.4. Capítulo IV: Modelización de la probabilidad de transacciones informadas en el mercado europeo del carbono

En el presente capítulo se adapta la metodología propuesta por Easley, Kiefer, O'Hara y Paperman (1996), a las particularidades del mercado europeo de derechos de emisión sobre CO_2. Dicha metodología, que se fundamenta en los modelos teóricos de Easley y O'Hara (1987, 1992), tiene como objetivo determinar la probabilidad de negociar con agentes informados. En este capítulo, adaptamos dicha metodología para poder estimar la probabilidad de negociación informada en los EUAs y los CERs alrededor de eventos que se producen regularmente en el mercado.[5]

Todos los años las compañías obligadas a rendir cuentas por sus emisiones, deben informar de sus emisiones efectivas correspondientes al año anterior como muy tarde el 31 de marzo. Los permisos correspondientes deben ser entregados a la Comisión Europea el 30 de abril de dicho año y ésta hace públicos los datos oficiales alrededor del 15 de mayo. Como consecuencia de dicho calendario, durante varios meses, las compañías obligadas tienen en su poder información que todavía no es pública, por lo que puede ser utilizada en su propio beneficio.

Con el objetivo de detectar prácticas con información privada, se ha construido una extensión del modelo propuesto por Easley, Kiefer, O'Hara y Paperman (1996), permitiendo a los operadores informados y no informados elegir entre los dos activos, a

[5] A pesar de que EUAs y CERs comparten el mismo objetivo, lo cierto es que los CERs están limitados en su uso, por lo que condicionan claramente su precio y sistemáticamente han mostrado niveles de precios por debajo del de los EUAs.

la hora de operar. El modelo plantea que proveedores de liquidez y especuladores interactúan durante *I* periodos. Al comienzo de cada periodo (o día), un evento que produce información privada puede ocurrir con probabilidad α. En caso de que ocurra, éste será positivo con probabilidad 1-δ y negativo con probabilidad δ. En un día sin ningún evento informativo, los operadores no informados lanzarán órdenes de compra y de venta al mercado con ratios ε_b y ε_s, respectivamente. En caso de que se produzca un evento informativo, los operadores informados lanzarán órdenes con intensidad μ, por lo que si la señal es positiva (negativa) las órdenes totales de compra (venta) vendrán determinadas por intensidad $\varepsilon_b+\mu$ ($\varepsilon_s+\mu$). Adicionalmente, tanto los operadores informados, como los no informados, deben decidir en el mercado si comercializarán EUAs o CERs. β, τ y φ marcan el porcentaje de las órdenes lanzadas por los operadores informados a favor de los CERs, el porcentaje de las órdenes lanzadas por los operadores no informados que compran CERs y el porcentaje de las órdenes lanzadas por los operados no informados que venden CERs, respectivamente.

Mediante la estimación por máxima verosimilitud del producto de todas las funciones específicas para cada uno de los días, se puede obtener tanto el valor teórico del *spread* de apertura como el valor de todos los parámetros del modelo que nos permitirán determinar qué porcentaje de las órdenes para EUAs y CERs provienen de operadores informados (PIN).

En este capítulo se han usado tanto datos diarios como intradiarios del mercado ICE ECX, centrándonos principalmente en las transacciones "*screen*" de los futuros con vencimientos en los meses de diciembre entre 2008 y 2014. Finalmente, los distintos vencimientos de los contratos de futuro se han enlazado para obtener tres series completas con los futuros de vencimiento diciembre más cercano, con los del segundo vencimiento diciembre más cercano y con los del tercer vencimiento diciembre más cercano, tanto para EUAs, como para CERs.

Nuestros resultados muestran que el PIN de los EUAs aumenta entre diciembre y marzo, tal y como era de esperar, mientras que los CERs muestran su máximo PIN en noviembre y diciembre. También observamos que la probabilidad de que ocurra un evento informado aumenta en abril. Poniendo hincapié en la evolución de las variables del modelo a lo largo del tiempo. Los resultados determinan que la probabilidad de que ocurra un evento informado ha disminuido a lo largo del tiempo, mientras que la probabilidad de que este evento sea negativo, ha aumentado. Se obtienen evidencias de que el PIN de mercado para los EUAs se ha mantenido estable a lo largo del tiempo, mientras que para los CERs ha aumentado, llegando en 2011 a ser muy parejo. Un análisis más individualizado por series muestra nuevamente que en general los EUAs exhiben niveles más altos de PIN que los CERs. Se observa, también, que la serie de vencimiento más cercano para los EUAs muestra niveles inferiores a la serie de vencimientos más lejanos. En cuanto a los CERs, su comportamiento es muy similar en las tres series estudiadas. El análisis de β, τ y φ, muestra una predilección por EUAs en el primer trimestre de 2009. En cuanto a los parámetros que marcan la intensidad de las ordenes, se observa un aumento de dicha intensidad en los segundos trimestres del año, consistente con los aumentos de volumen de abril y mayo, y los futuros con vencimiento más lejano muestran en 2011 mayores volumen en términos porcentuales, que en los años previos. El porcentaje de operaciones informadas muestra menores niveles en los vencimientos más cercanos. En cuanto al modelo, se rechazan las hipótesis de que τ=φ, y que β, τ y φ son iguales a lo largo de las diferentes series, lo que implica que los agente no informadas ponderan de forma distinta su predilección por EUAs y CERs, a la hora de comprar y vender, y que las predilecciones por EUAs y

CERs cambian dependiendo del contrato en el que estén operando tanto los agentes informados, como los no informados. Por último, los resultados muestran que las horquillas teóricas de apertura de los precios para EUAs y CERs se han visto afectadas por la actual crisis financiera, y que en general las horquillas en precios han sido menores en CERs, que en EUAs, aunque en 2011 las diferencias han disminuido considerablemente.

Las conclusiones de este capítulo sugieren que la importancia del CER ha aumentado considerablemente en el mercado de derechos de emisión en los últimos años y que en la actualidad atrae la atención de un gran número de agentes. Por tanto, los CERs deberían ser considerado por los operadores, los investigadores y los reguladores en el análisis de carteras, en los proyectos de investigación y en las decisiones regulatorias, respectivamente. Paralelamente, las ineficiencias detectadas en los meses previos a la publicación de las verificaciones anuales de las emisiones de CO_2, destacan la necesidad de ser consideradas y mitigadas en la medida de lo posible por los reguladores, con el objetivo de aumentar la eficacia y la transparencia del mercado y garantizar la protección de los agentes externos.

2. Conclusiones

En esta tesis doctoral se ha analizado en profundidad el mercado europeo de derechos de emisión sobre CO_2, haciendo hincapié en los dos principales activos negociados: *European Union Allowances* (EUAs) and *Certified Emission Reductions* (CERs).

2.1. Conclusiones principales

I. Las propiedades estadísticas de los rendimientos de los EUAs sugieren que estamos ante una nueva clase de activo.

II. Sugerimos que la metodología más simple para enlazar contratos, que consiste en pasar de uno a otro en el último día de negociación del primero, debería ser empleada en los estudios empíricos que trabajan con las series de precios de los EUAs y CERs.

III. La calidad de los precios de los EUAs se ha visto afectada dramáticamente por el colapso en precios al final de la Fase I y la posterior crisis financiera. Además a finales de 2010 la calidad sigue por debajo de los niveles observados al principio de 2006.

IV. Se han obtenido evidencias de incrementos significativos en la actividad de los operadores informados, entre los meses de diciembre y marzo de cada año, en los EUAs, y al final del año en los CERs.

2.2. Conclusiones secundarias

I. Se han observado determinadas propiedades estadísticas en las series de los EUAs tales como, la existencia de casos extremos, la gaussianidad en los rendimientos agregados, el *Taylor effect*, concentraciones en volatilidad, volatilidad asimétrica, una relación positiva entre volatilidad y volumen, y volatilidad y *open interest*, una dependencia temporal (implica la necesidad de modelizar con estructuras ARMA-GARCH), asimetría negativa de los rendimientos, correlación positiva con los índices sobre acciones, mayor volatilidad a lo largo de la sesión, la posibilidad de cobertura frente a la inflación no esperada y correlación negativa con activos de renta fija.

II. El análisis de liquidez con distintos criterios para enlazar series de contratos, muestra que las metodologías basadas en el número de posiciones abiertas no son adecuadas en los estudios de liquidez.

III. La calidad de los precios del ICE ECX no ha variado excesivamente entre la Fase I y la Fase II. A pesar de que en la Fase II observamos mayor intensidad en el número de transacciones, menores costes por operación, menores asimetrías de información, menor volatilidad en los precios y menor volatilidad de las fricciones, la contribución de las fricciones a la volatilidad total ha estado presente en la Fase II por encima de los niveles observados en la Fase I.

IV. Se ha confirmado el liderazgo del futuro con vencimiento diciembre más cercano, a pesar del aumento en importancia de aquellos contratos con vencimientos más lejanos, y se han obtenido evidencias de la importancia creciente de los CERs en el mercado europeo de derechos de emisión sobre CO_2.

3. Líneas de investigación futuras

Los resultados obtenidos en la tesis doctoral han dado respuestas a diversas cuestiones planteadas pero no resueltas en la literatura existente concernientes al mercado europeo de derechos de emisión sobre CO_2. No obstante, en mi opinión es necesaria más investigación en el campo de la microestructura y la eficiencia de dicho mercado.

Un enfoque clave para el futuro sería el desarrollo de métodos estadísticos para la detección de prácticas de manipulación en precios y probar su eficacia en el mercado europeo de los derechos de emisión sobre CO_2. A pesar de que la manipulación es ilegal, diversos estudios han probado de forma teórica y empírica que la manipulación del mercado es posible. En algunas ocasiones las autoridades han detectado dichas prácticas, pero en otras, habiendo indicios, no ha sido posible. Se propone extender el modelo propuesto por Allen y Gale (1992) y adaptarlo a las particularidades del mercado europeo de derechos de emisión sobre CO_2. Allen y Gale (1992) exponen un modelo de expectativas racionales con asimetrías de información, donde todos los agentes maximizan su utilidad esperada, en un número finito de periodos. En esta economía el "manipulador" simplemente compra y vende una acción en un único mercado, donde la manipulación por parte de la compañía o los falsos rumores, no están permitidos. Existen dos tipos de inversores: los inversores pasivos (aversos al riesgo) y los grandes inversores (riesgo neutrales), donde éstos últimos se dividen en dos categorías, en operadores informados y en manipuladores (no informados). Los inversores no pueden determinar si las órdenes de gran volumen vienen lanzadas por los operadores informados o por los manipuladores. Dos activos coexisten en el mercado, una acción y dinero. El primer activo tomará un valor "alto" o "bajo" al final del último periodo con unas probabilidades dadas, mientras que el segundo activo es un activo libre de riesgo y de rentabilidad nula. La negociación se produce en tres etapas, donde inicialmente los inversores poseen todas las acciones. En la primera etapa los agentes informados entran en el mercado sólo si anticipan un anuncio, mientras que los manipuladores entran si no esperan noticias. Si un evento informado ocurre, las noticias negativas son reveladas antes que las positivas. Finalmente, todos los operadores maximizan la utilidad esperada de su riqueza final. Los resultados muestran que la manipulación es posible, aunque no se tomen acciones que alteren el verdadero valor de la compañía o se difundan noticias falsas al mercado. Adicionalmente, cuando las creencias de los inversores son que el operador es un informado, la manipulación es más rentable.

Tras probar la existencia de asimetrías de información en el mercado y la utilización de información privada, la detección de prácticas manipuladoras en precios evaluaría otro tipo de ineficiencia presente en el mercado.

Un segundo trabajo de investigación que se propone trataría el uso y/o la extensión (con las particularidades del mercado europeo de emisiones), de la metodología propuesta por Easley, López de Prado y O'Hara (2012), con el objetivo de verificar cómo se comportaron las transacciones "informadas" en pequeños espacios de tiempo, cerca de eventos específicos ocurridos en el mercado europeo de emisiones, tales como el anuncio de los Planes Nacionales de Asignación (NAPs en sus siglas en inglés), y otros eventos relevantes concernientes a la Fase III. Easley, López de Prado y O'Hara (2012) toman en consideración el volumen negociado y el momento en el que se produce la transacción, con el objetivo de estimar la toxicidad de las órdenes mediante datos intradiarios. El modelo de negociación secuencial asume que las transacciones informan acerca del "verdadero" valor futuro de un activo y su magnitud influye en el movimiento futuro de los precios. Cuanto más relevante sea una noticia, más volumen atraerá. La metodología propone agrupar el volumen en paquetes de igual magnitud, donde a través del signo de las transacciones incluidas en cada paquete, se identifican los desequilibrios entre transacciones y se deriva una medida de toxicidad de las órdenes denominada VPIN o "*volume-synchronized probability of informed trading*".

Finalmente, los análisis realizados en los capítulos I y III podrían ser extendidos mediante la aplicación de las metodologías empleadas a los CERs y su posterior contraste con los EUAs, y la utilización de otras propiedades estadísticas y metodologías a ambos activos. En cuanto al Capítulo II, un completo análisis de la Fase III sería de gran ayuda para futuros investigadores del mercado europeo de emisiones.

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