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The Timeline of Trading Frictions in the European Carbon Market^{*}

Vicente Medina, Ángel Pardo and Roberto Pascual^{**}

Abstract

We evaluate the quality of prices of the EU-ETS, the most active European derivative market for greenhouse gas emissions allowances (EUAs). So far, this market has had two phases, a trial phase (from 2005 to 2007) and a commitment phase (from 2008 to 2012). The true value of a trial-phase EUA at the beginning of 2008 was inevitably zero because it could not be used in the commitment phase to cover emission targets. However, continued rumors of over-allocation of EUAs led to an early collapse of the market by May 2007. We study whether this market breakdown and the subsequent outbreak of the international financial crisis had a persistent effect on the quality of the commitment phase. We provide robust evidence of substantial improvements in terms of liquidity, adverse selection costs, and friction-related volatility from the trial phase to the commitment phase. However, price quality (the proportion of friction-unrelated price return volatility) during the commitment phase 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.

Keywords: Greenhouse gas emissions, EUAs, European Union Emission Trading Scheme, trading frictions, price efficiency, liquidity, financial crisis, market breakdown, market microstructure.

JEL classification: G1.

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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 friction 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 CO₂ 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 CO₂ or an equivalent amount of certain greenhouse gases. The installations covered by the EU-ETS receive an initial endowment of emission credits through the National Allocation Plans (NAPs). 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. ECX futures contracts on EUAs attract most of the exchange-traded volume in the EU-ETS.

In this study, we consider the first two phases in the so far short history of the EU-ETS, the trial phase or "Phase I", that traded emissions from 2005 to 2007, and the current commitment phase or "Phase II", that covers emissions from 2008 to 2012. Phase I is generally considered a pilot or learning period (see Creti et al. (2011) and Ellerman and Buchner (2006), among others). Phase II concurs with the Kyoto Protocol accomplishment period. A particularity of this market is that EUAs of the trial phase could not be used to comply with the emission targets during the commitment phase (i.e., inter period *banking* is not allowed). Therefore, a EUA of Phase I is a different asset than a EUA of Phase II.

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.

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 CO₂ emissions, had a severe negative effect on the EUAs prices by the beginning of 2009. In this paper, we study whether the collapse of the trial phase and the subsequent rash of the international financial crisis had a persistent negative effect on the quality of the commitment phase, 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 specification may be highly satisfactory to describe the dynamics of prices sampled at

³ Ellerman and Buchner (2006) argue that earlier before these official statistics were revealed, observers recognized that the cap on CO₂ 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 CO₂ 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 CO₂ prices into their production decisions.

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

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, Richardson, and Roomans (1997) (hereafter MRR) 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. The database covers Phase I and large part of Phase II (till 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 the trial phase, 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 the commitment phase, all of these suggesting improved trading conditions during the commitment phase. 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 the commitment phase. 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 EU-ETS. Using Phase I data on EUA futures, Benz and Hengelbrock (2008) compare ECX and Nord Pool 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, Chevalier and Sevi (2009) characterize the conditional and unconditional distributions of realized volatility for ECX futures. Conrad et al. (2011) focus on modeling the dynamics of EUA prices from November 2006 to December 2008 using GARCH-type models. Mizrach (2010) 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 (2011) 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 commitment period 2008-2012. Because of the Kyoto Protocol, carbon trading has been growing continuously.⁵ As part of its "Flexibility Mechanisms", the article 17 of the Kyoto Protocol establishes the need to create an emission trading mechanisms to negotiate the different emission credit units among countries.

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 regulates 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 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

⁵ There are several types of GHG, but the CO₂-equivalent is used as a unit of measurement. GHG are listed in the Annex A of the Kyoto Protocol.

installations/countries that fail in complying with their emission targets are more likely to act as buyers of emission credits.

Under the EU-ETS, each Member State must prepare 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 must be presented no later than 18 months before the start of each “Phase”, and it must be approved by the European Commission.⁶ Accordingly, each Member State decides about how the emission credits are yearly allocated among the installations covered and about the possibility of banking and borrowing credits among phases.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. The emission credits distributed among the companies covered by the 2003/87/EC Directive are called European Union Allowances (EUAs).⁸

The EU-ETS officially started on January 1st, 2005. In order to neutralize irregular CO₂ 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 2012.⁹ 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.

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.

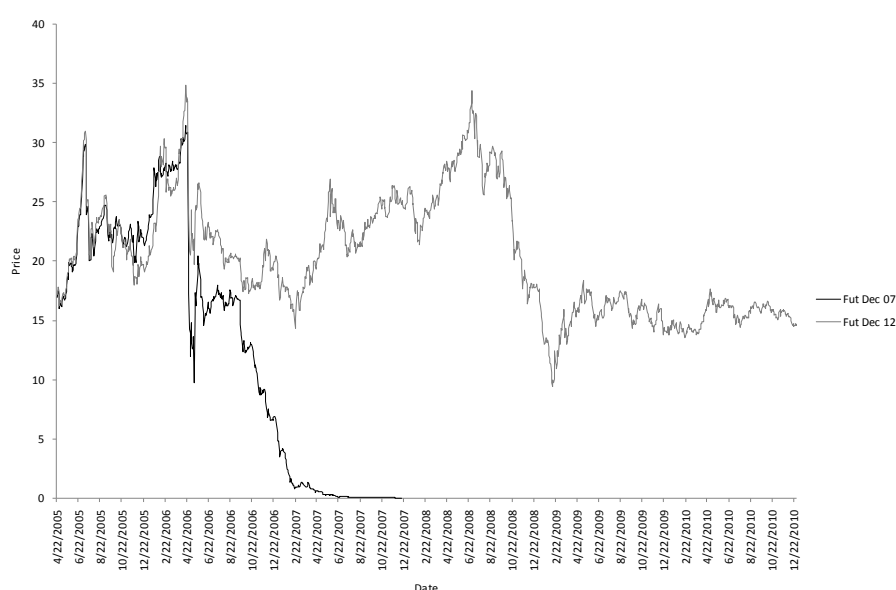
⁸ Other types of emission credits to be imported into the EU-ETS are fully fungible with EUAs. The 2004/101/EC Directive of the European Parliament (so called 'Linking Directive') allows EU members to use Kyoto certificates from the so-called "project-based flexible mechanisms" to cover their domestic 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.

⁹ There will be at least a Phase III, from January 1st, 2013 to December 31st, 2020.

In Figure 1, we plot the time series of future prices for two contracts: Phase I EUA future with expiry in December 2007 and Phase II EUA future with expiry in December 2012 (until December 2010). 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.

FIGURE 1
Future and spot prices for EUAs

We plot the time series of future prices for two contracts: Phase I EUA futures with expiry in December 2007 and Phase II EUA futures with expiry in December 2012 (until December 2010).



As previously mentioned, Phase I was 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. 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 mark 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 CO₂ 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 CO₂ 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 CO₂. However, this factor was more than offset by the economy's recession. [...] Experience shows that in a recession, CO₂ 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 activity in the EU-ETS is fragmented through different markets around Europe. In all cases, the assets traded are Phase I and II EUAs.¹⁰ During Phase I, spot trades of Phase II EUAs were not

¹⁰ Spot markets include BlueNext (Paris), which is part of NYSE-Euronext since December 2007, Energy Exchange of Austria (Vienna), Nord Pool (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), Nord Pool, EEX, and BlueNext only in Phase II. Options on EUAs are also traded in some of the previous markets, such as ECX.

possible; futures on Phase I and Phase II EUAs, however, were both simultaneously traded.¹¹

Table I provides statistics on total trading volume in lots (1,000 tonnes of CO₂ 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. ECX EUAs Daily Futures (“spot”) were introduced in March 2009. In two years, the ECX spot market has 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.

TABLE I
Market shares

This table reports yearly market shares of the two most representative markets 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 CO₂ equivalent.

Panel A: Spot Market

Year	Phase I*	Shares		Phase II	Shares		ECX	Others
	Total (lots)	BlueNext	Others	Total (lots)	BlueNext			
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

Year	Phase I	Shares		Phase II	Shares		ECX	Others
	Total (lots)	ECX	Others	Total (lots)	BlueNext			
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%

* NordPool data not available.

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

¹¹ 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 (Nord Pool).

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 Participant'). Trading may also be conducted by a Member's clients ('order routing') where 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.¹² 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 CO₂ equivalent, that is, 1,000 EUAs. The minimum tick size for all contracts is €0.01.¹³

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 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

¹² Before January 9th, 2006, the continuous session run between 08:00 a.m. and 5:00 p.m.

¹³ Before March 27th, 2007, the tick size was €0.05.

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 Future 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 2005.¹⁴ The quotation is in Euros per tonne and the unit of trading is one lot or 1,000 EUAs. 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.¹⁵

In Table II, we report some summary statistics on the trading activity of the different ECX EUA future contracts both in 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.

¹⁴ The first EUA daily future or "spot" contract was issued on March 13th, 2009. We will ignore the spot market in this paper because of this late start.

¹⁵ 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.

TABLE II
Trading activity per future contract

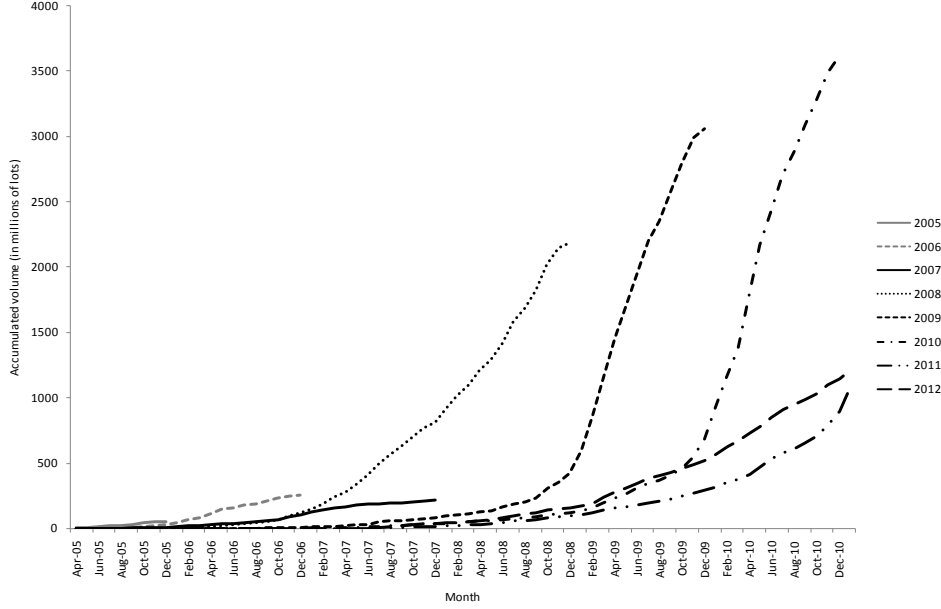
This table provides statistics on trading activity for the different ECX EUA future contracts both in Phase I and Phase II.

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	12/19/2005	12:35
1	Mar-06	476	24.76	7,7	16.18	10/11/2005	16:10	3/24/2006	16:57
1	Jun-06	43	22.47	879	20.44	1/9/2006	12:02	6/23/2006	7:08
1	Sep-06	10	16.33	220	22	7/18/2006	13:45	9/19/2006	12:46
1	Oct-06	8	12.63	80	10	10/13/2006	12:23	10/19/2006	8:15
1	Nov-06	4	15.01	80	20	7/25/2006	15:37	10/30/2006	9:43
1	Dec-06	20,855	18.12	248,6	11.92	4/28/2005	9:30	12/18/2006	16:19
1	Jan-07	3	18.88	30	10	12/29/2006	10:37	1/9/2007	16:51
1	Feb-07	1	1.6	25	25	2/9/2007	17:15	2/9/2007	17:15
1	Mar-07	70	4.39	8,638	123.4	1/19/2006	12:22	3/26/2007	16:27
1	Jun-07	1	0.19	200	200	6/13/2007	11:29	6/13/2007	11:29
1	Dec-07	13,541	8.5	213,636	15.78	4/26/2005	10:30	12/17/2007	16:13
2	Jan-08	14	20.62	300	21.43	3/15/2007	18:05	1/24/2008	17:21
2	Feb-08	24	90.18	24	1	1/18/2008	18:10	1/21/2008	12:19
1	Mar-08	42	1.96	1,838	43.76	2/2/2006	13:44	3/31/2008	15:59
2	Dec-08	238,647	21.93	2,188,980	9.17	6/17/2005	16:04	12/15/2008	16:41
2	Mar-09	170	11.47	11,905	70.03	12/1/2008	11:15	3/30/2009	15:17
2	Jun-09	4	17.95	105	26.25	11/6/2008	15:47	4/24/2009	15:46
2	Sep-09	28	14.11	796	28.43	5/27/2009	14:19	9/25/2009	16:26
2	Dec-09	312,130	13.85	3,057,609	9.8	10/12/2005	13:20	12/14/2009	17:17
2	Mar-10	32	13.81	1,804	56.38	9/4/2009	14:46	3/19/2010	11:46
2	Jun-10	8	14.85	335	41.88	2/17/2010	17:03	6/28/2010	15:23
2	Sep-10	14	15.07	390	27.86	4/15/2010	16:32	9/24/2010	9:32
2	Dec-10	289,726	14.57	3,078,319	10.62	1/26/2006	17:05	9/27/2010	16:48
2	Mar-11	9	15.17	454	50.44	3/10/2010	12:35	6/15/2010	16:07
2	Jun-11	3	15.67	75	25	5/6/2010	14:37	5/11/2010	13:50
2	Sep-11	3	15.78	75	25	5/6/2010	14:37	5/11/2010	13:51
2	Dec-11	49,427	15.46	652,982	13.21	3/23/2006	13:39	9/27/2010	16:12
2	Mar-12	5	15.7	137	27.4	4/14/2010	12:34	6/8/2010	11:53
2	Jun-12	3	15.71	75	25	4/14/2010	12:34	5/11/2010	13:48
2	Sep-12	3	15.88	75	25	4/14/2010	12:35	5/11/2010	13:47
2	Dec-12	50,650	16.6	981,907	19.39	3/22/2006	17:21	9/27/2010	16:44

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 the trial phase. Figure 2 also shows that ECX trading activity has increased overtime.

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 date in December 2005 to 2012.



3. The database

In our empirical analysis, we use high frequency data provided by ECX covering all Phase I (from April 22nd, 2005) and part of the current Phase II (until December 31st, 2010) of the EU-ETS. Our database consists on 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 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.

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 CO₂ 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	4/22/2005	4/22/2005 7:00	12/19/2005	12/19/2005 12:35	169	28.31	0.0489	20.43
1	Dec. 2006	4/22/2005	4/28/2005 9:30	12/18/2006	12/18/2006 16:19	423	49.30	0.0858	11.65
1	Dec. 2007	4/22/2005	4/26/2005 10:30	12/17/2007	12/17/2007 16:13	679	19.94	0.0341	29.28
2	Dec. 2008	4/22/2005	6/17/2005 16:04	12/15/2008	12/15/2008 16:41	934	255.51	0.4347	2.30
2	Dec. 2009	4/22/2005	10/12/2005 13:20	12/14/2009	12/14/2009 17:17	1,188	262.74	0.4454	2.25
2	Dec. 2010	4/22/2005	1/26/2006 17:05	12/20/2010	12/20/2010 16:59	1,447	228.33	0.3862	2.59
2	Dec. 2011	4/22/2005	3/23/2006 13:39	12/31/2010	12/31/2010 11:59	1,454	44.17	0.0748	13.38
2	Dec. 2012	4/22/2005	3/22/2006 17:21	12/31/2010	12/31/2010 11:59	1,454	39.96	0.0676	14.78
1	Rollover	4/22/2005	4/22/2005 7:00	3/31/2008	3/31/2008 15:59	750	42.81	0.0732	13.66
2	Rollover	4/22/2005	6/17/2005 16:04	12/31/2010	12/31/2010 11:59	1,454	562.81	0.9525	1.05

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.¹⁶ 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 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, 2007.¹⁷ Phase II time series covers from June 17th,

¹⁶ We have considered alternative rollover criteria. We find that the distribution properties of the resulting time series are not affected by our selection. These analyses are available upon request.

¹⁷ 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

2005, to December 31st, 2010. These time series for Phase I and Phase II are the main input of our posterior analysis.

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 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.

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.

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

EXC trade type	Future Phase I		Future Phase II	
	# 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

EXC trade type	Future Phase I		Future Phase II	
	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

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.¹⁸

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

¹⁸ 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).

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 contest, 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., $m_t = E(\mathfrak{I}_T | \Phi_t)$. 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 $\eta_t \sim iid(0, \sigma_\eta^2)$. In a frictionless market, the actual trade prices (p_t) are always equal to m_t .

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,

$$Cov_{\Delta p} = Cov(\Delta p_t, \Delta p_{t-1}) = E[\Delta p_t \Delta p_{t-1}] = \frac{-S^2}{4}.^{19} \quad (1)$$

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

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

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

¹⁹ 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.

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 $Q^R = \sigma_\eta^2 / (\sigma_\eta^2 + 0.5S^2)$.

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 $\eta_t = \alpha(S/2)x_t + u_t$, where u_t is an innovation due to public news, and α is the adverse selection costs parameter. Let $E[x_{t-i}u_{t-j}] = 0, \forall i, j$, 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 $\Pr(x_t \neq x_{t-1} | \Phi_{t-1}) = \pi = 1/2$. With the additional assumption that quotes are ex-post rational, as in Glosten and Milgrom (1985), $p_t = q_t + (S/2)x_t$, where $q_t = m_{t-1} + u_t$ is the quote midpoint. With this price decomposition, $\alpha(S/2)$ and $(1-\alpha)S/2$ are the adverse selection costs component and the real friction component of the spread, respectively. Given that,

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

the relevant parameters can be recovered from the estimated coefficients of the regression equation $\Delta p_t = b_0 + b_1x_t + b_2x_{t-1} + e_t$, where expected values are $b_0 = 0$, $b_1 = S/2$, $b_2 = -(1-\alpha)(S/2)$ and $Var[e] = \sigma_u^2$. From (3), $Cov_{\Delta p} = -(1-\alpha)^{-0.5} 0.25S^2$, meaning that Roll's bid-ask spread estimator underestimates the true spread whenever $\alpha > 0$. Regarding quote quality, the variance of Δp_t in (3) is

$$Var(\Delta p_t) = \sigma_u^2 + 0.25S^2[2(1-\alpha) + \alpha^2]. \quad (4)$$

The second RHS term of (4) is friction-related. Because $Var(\Delta m_t) = \sigma_u^2 + 0.25S^2\alpha^2$, it turns out that $0.5S^2(1-\alpha)$ is the only fraction of (4) that is transitory (i.e., noisy) in nature. From (4) we can see that, unless $\alpha = 0$, 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

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

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, $\pi \neq 1/2$.²⁰ 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 $Var(\Delta p_t) = \sigma_u^2 + 0.25S^2[4\pi(1 - \alpha) + \alpha^2]$, 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.

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 $w_t = x_t - E[x_t | x_{t-1}]$ 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 $u_t \sim iid(0, \sigma_u^2)$ 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 $\xi_t \sim iid(0, \sigma_\xi^2)$ is an innovation that accounts for rounding errors and price discreteness.²¹ 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

²⁰ 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).

²¹ The parameter θ can be seen as $\alpha(S/2)$ and ϕ as $(1 - \alpha)(S/2)$, so that the implicit spread $S = 2(\theta + \phi)$.

costs; $2(1-\rho)\phi^2$, due to real frictions, and $2\phi\theta(1-\rho^2)$, an interaction term.²² In this model, our measure of quality of prices is given by $Q^{MRR} = \sigma_u^2 / \text{Var}(\Delta p_t)$, where $\text{Var}(\Delta p_t)$ is given by (6). Finally, under the assumption that $w_{t-1} = -1$ and $w_t = 1$, the expected realized spread is $E(S^r) = 2[2\pi(\phi + \theta) - \phi]$. Madhavan et al. (1997) suggest estimating the model parameters $\{\theta, \rho, \phi, \sigma_u^2, \sigma_\varepsilon^2\}$ 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.²³ 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 $\{r_t, x_t, x_t^s, x_t^{s1/2}\}$, 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 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 .²⁴ The VAR model is truncated at 3 lags.²⁵

²² In Madhavan et al.'s (1997) original model specification, the authors account for the possibility of transaction prices within the spread (price improvements). In ECX, price improvements are not possible, so we simplify the model accordingly.

²³ 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.

²⁴ 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.

²⁵ We have also considered time series models truncated at 5 lags. Our main findings are basically the same.

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 to September 30th, 2005 and from July 1st 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.

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

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 3,499 (last quarter of 2006). During Phase II, 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 of 2010).

During Phase I, the median volume traded per quarter was 17,867 lots, while during Phase II it was 57,428 lots. The median net volume (buyer-initiated minus seller-initiated) per quarter was negative (-1,171 lots) during Phase I and positive (3,466 lots) during 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.²⁶

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 and 0.0160€ during Phase II. The negative slopes in the S trend for Phase II EUA futures, during both the trial and the commitment phases, are corroborated by the statistical tests in Panel C. During the trial phase, S was statistically higher than during the commitment phase, 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 2 (2008) was 0.0363€, but it increases to a median of 0.0491€ if all the commitment phase is considered.

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 the trial phase the median relative spread was 0.2%, 0.13% during 2008 and 0.06% by the end of 2010. The maximum relative spread of the commitment phase, 0.25%, was achieved during the first quarter of 2009.²⁷ Statistical tests in Panel C confirm that the relative spread was higher during the trial phase, even before the collapse, than during the commitment phase (both during 2008 and after 2008). The median difference between both phases was 0.36%.

²⁶ 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.

²⁷ 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.

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) with adverse-selection costs			
Roll (1984) original model							
Quarter	Year	S	Relat. S	α	S	αS	($\alpha S/P$)%
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							
<i>Average trend of Phase II EUAs (%):</i>							
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
<i>Mann-Whitney U-test PI vs. PII EUAs:</i>							
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
<i>Mann-Whitney U-test PII EUAs:</i>							
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.

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 the trial phase and 0.0186€ during the commitment phase. 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 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 the trial phase. 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 the trial phase, 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.

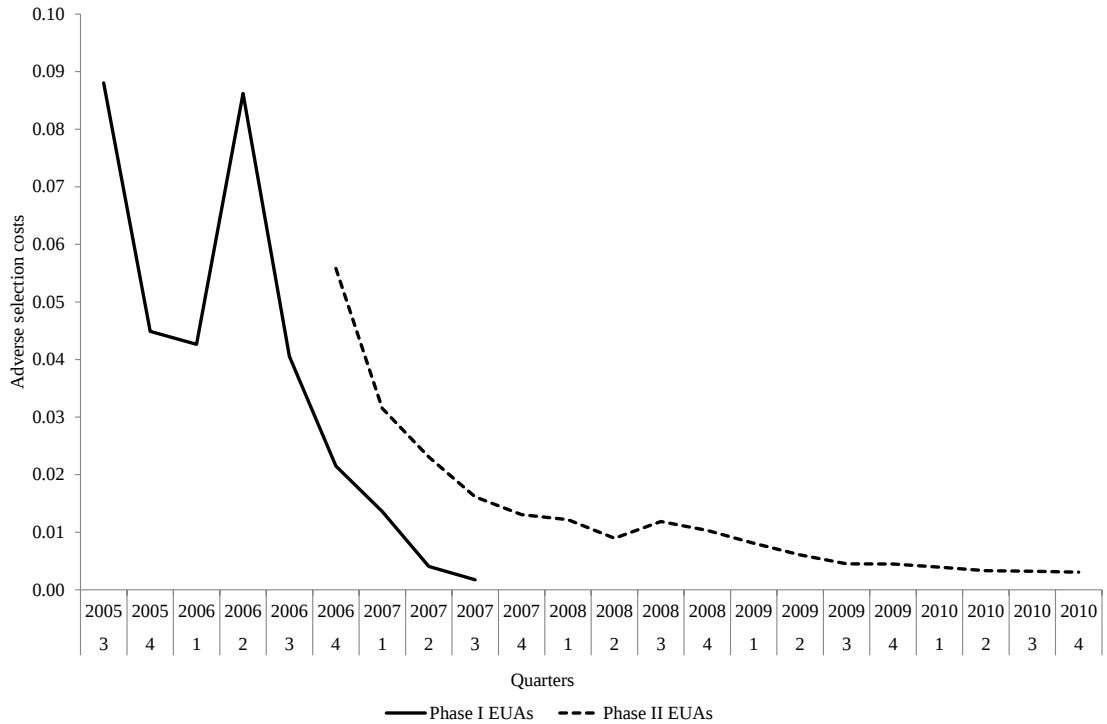
Finally, we also include in Table VII the ASC expressed in relative terms to the average future price during each quarter. The median relative ASC for Phase I EUA futures were 0.24% before the market collapse and 0.74% during 2007; for Phase II EUA futures, the median relative ASC dropped from 0.11% 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% (1st 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 the trial and the commitment phases, 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 beginning 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.²⁸ Figure 4(b) also shows that information-related frictions caused systematically less volatility than real frictions.

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

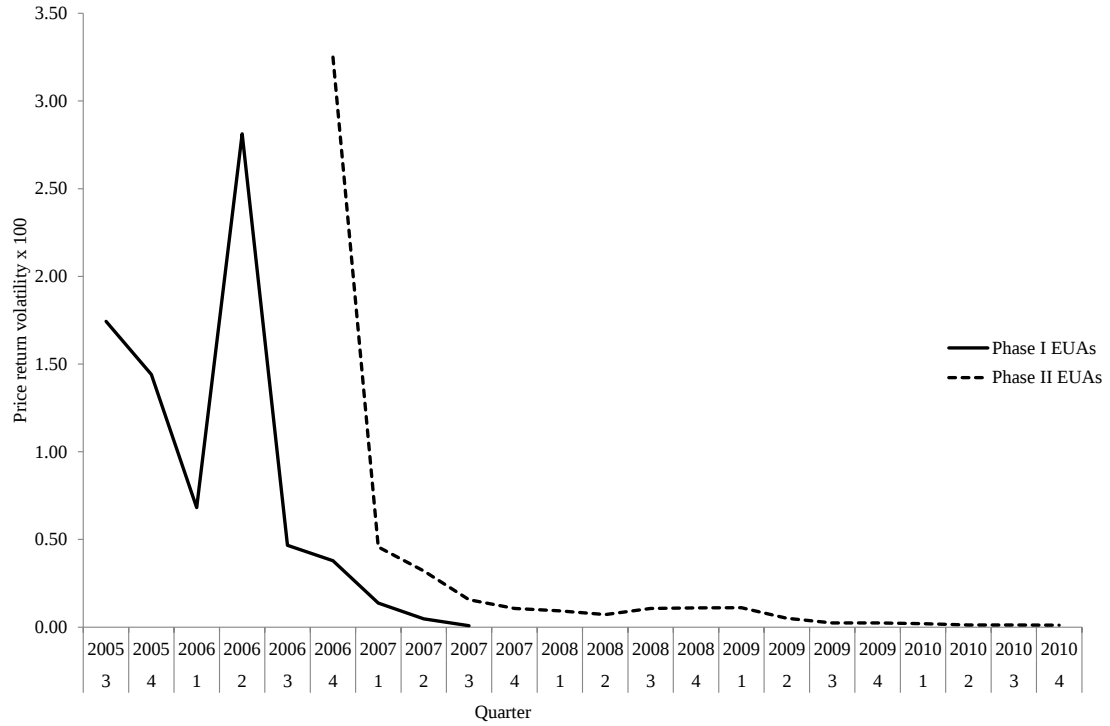
We plot the adverse selection costs evolution through time according to Roll (1984) model extended to account for information asymmetries.



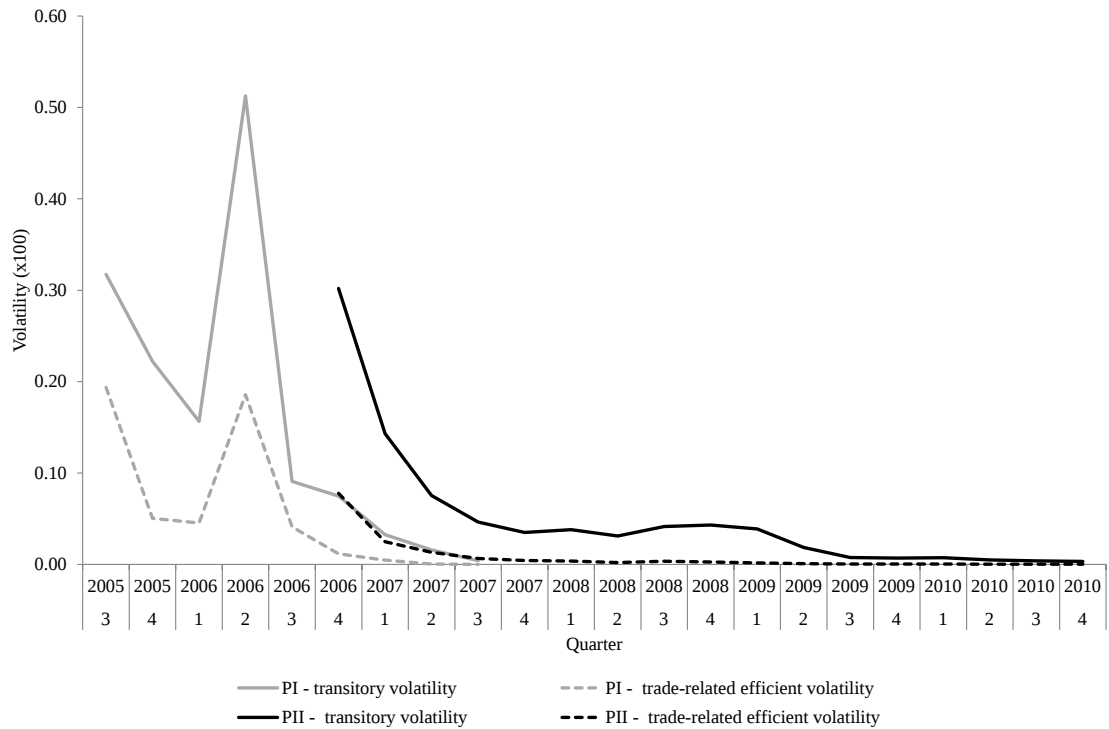
²⁸ These tests are available upon request from the authors.

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

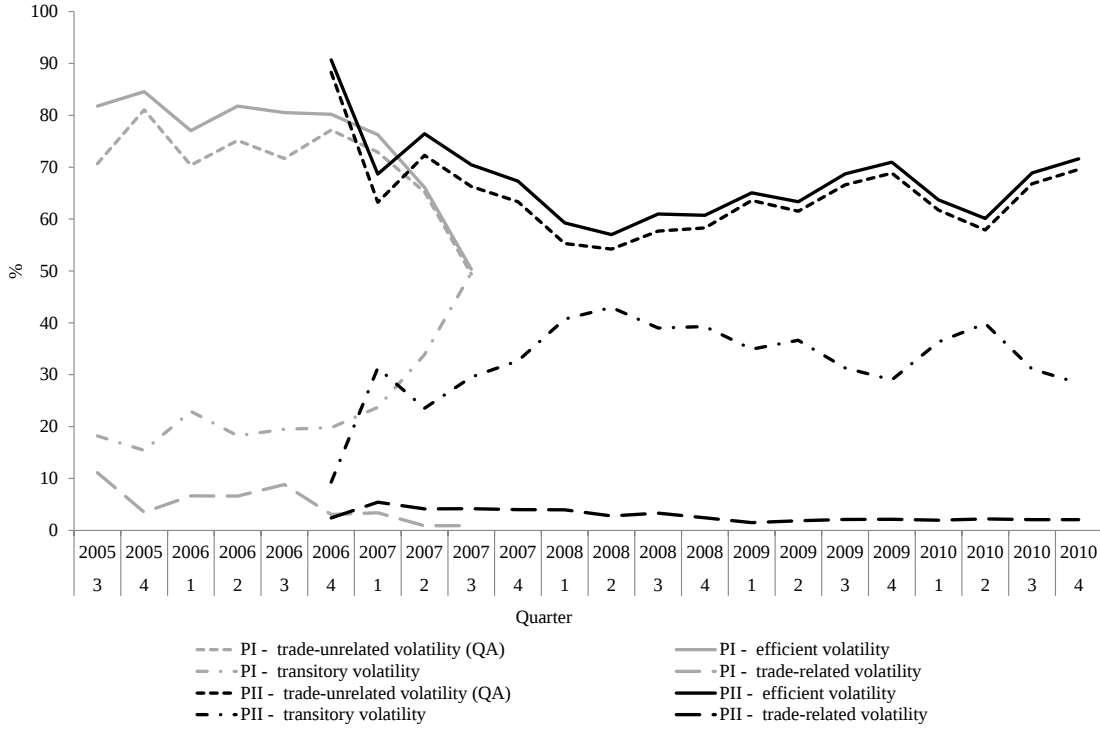
In Figure 5, we show the quarterly time series of the components of the return volatility as a proportion of the total volatility, according to Roll (1984) with ASC. Grey (black) curves represent Phase I (II) EUA futures. The contribution of the efficient volatility (σ_m^2) decreased to a global minimum of 50.32% at the end of Phase I, during the market collapse, suggesting a lot of noise in 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.

For Phase II EUA futures, the contribution of efficient (transitory) volatility during the commitment phase was 16.7% lower (higher), in median terms, than for Phase I EUA futures (p-value 0.0001). During the commitment phase, 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 the commitment phase) 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, $\sigma_u^2 / \text{Var}(\Delta p_t)$, 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).

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.



Next, we consider Madhavan et al. (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) shows 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 the trial phase, 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 the trial phase, $E(S^r)$ 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 the commitment phase: the median difference in $E(S^r)$ between Phase I EUA futures before the collapse and Phase II EUA futures during the commitment phase 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 the trial phase and the commitment phase 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 the trial and the commitment phases, 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.

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

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

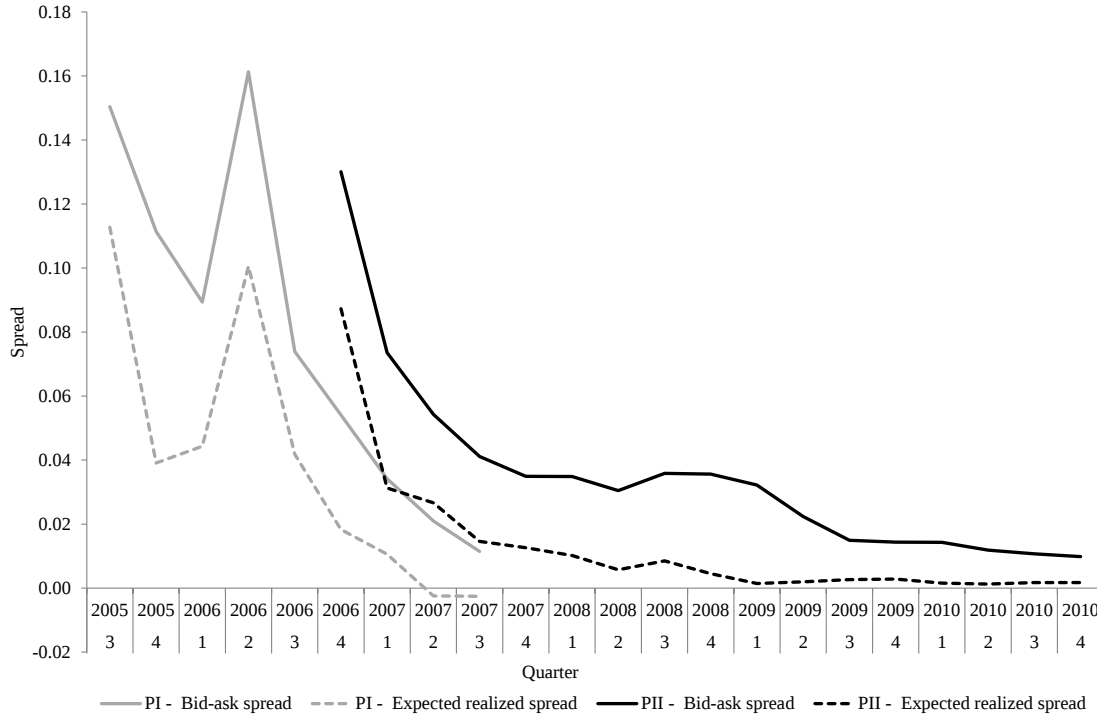
Panel C: Tests

	θ	ϕ	ρ	π
<i>Average trend of Phase II EUAs ($\times 100$):</i>				
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
<i>Mann-Whitney U-test PI vs. PII EUAs:</i>				
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
<i>Mann-Whitney U-test PII EUAs:</i>				
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 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.



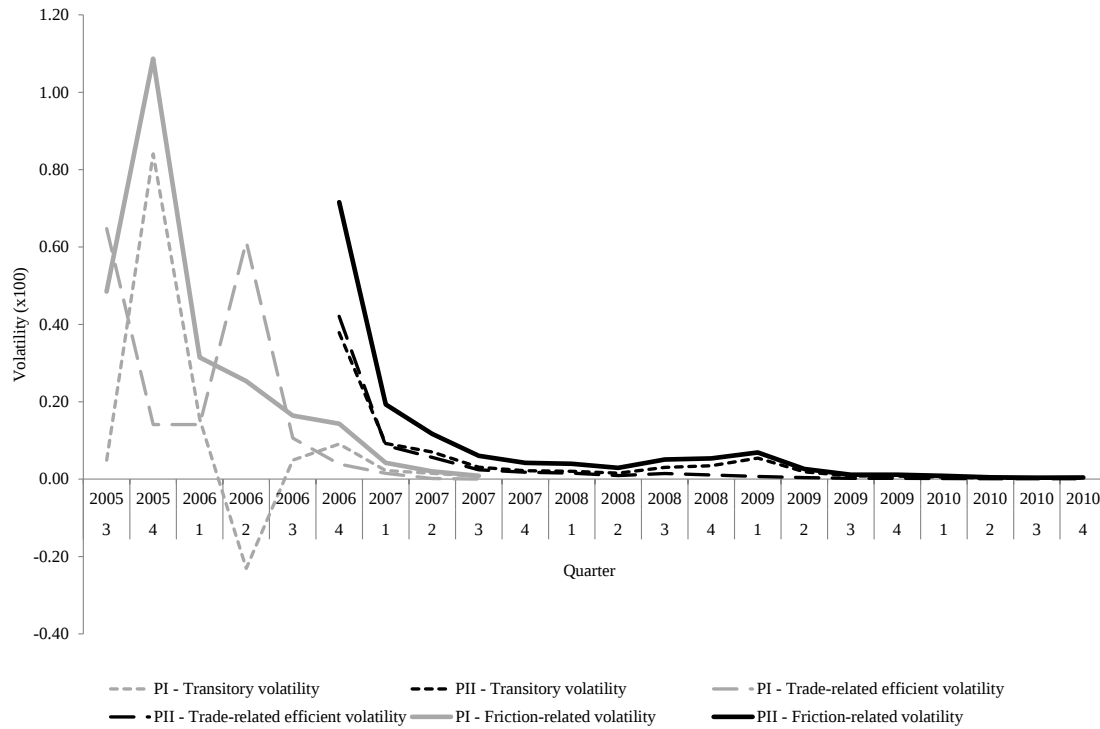
In Figure 7, we show the estimated friction-related volatility and its components based on the MRR model. Transitory volatility is the sum of the real frictions component and the price discreteness component, that is, $2\sigma_{\xi}^2 + 2(1-\rho)\phi^2$. Trade-related efficient volatility is due to ASC, that is, $(1-\rho^2)\theta^2$.²⁹ 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 the trial phase than for Phase II EUA futures during the commitment phase. 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

²⁹ The friction-related volatility includes also the interactive term. Its contribution, however, is negligible.

to a median 0.0189% (0.0453% in 2008 and 0.0098 afterwards). For Phase II EUA futures, real and information-related frictions were equally relevant in absolute terms.³⁰ 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.

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.



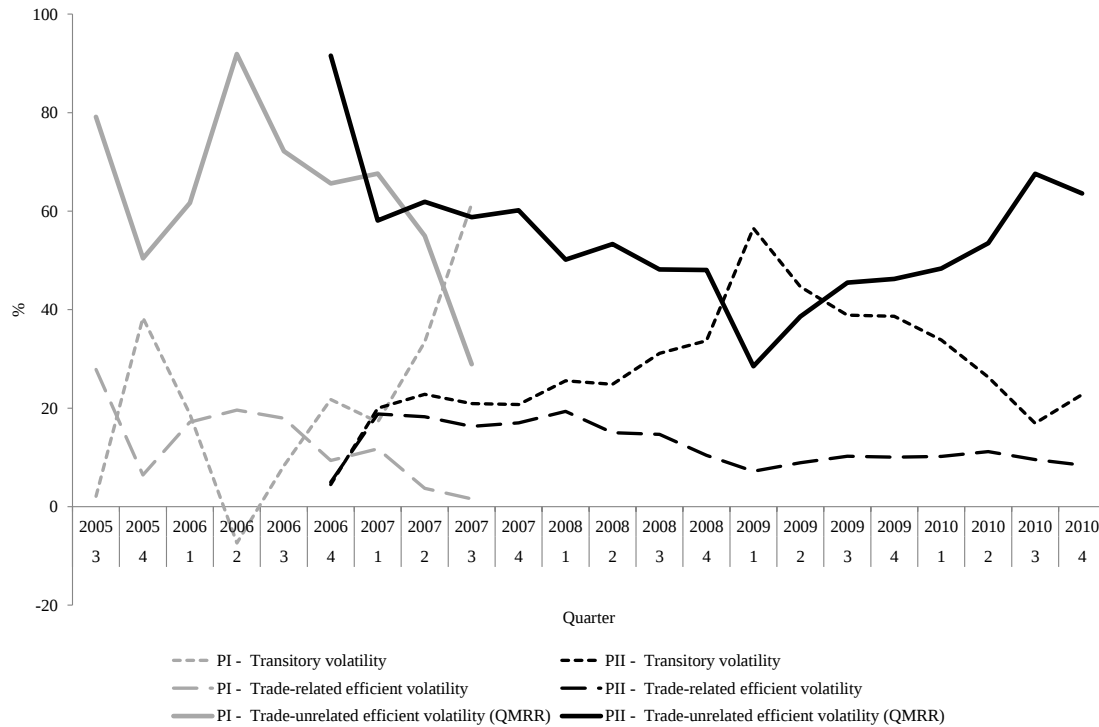
In Figure 8, we plot the quarterly time series of the estimated theoretical volatility components as a proportion of the total estimated volatility of price returns. As in prior figures, grey (black) lines represent Phase I (II) EUA futures. Solid lines

³⁰ 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.

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 $Var(\Delta p_t)$ 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.

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.



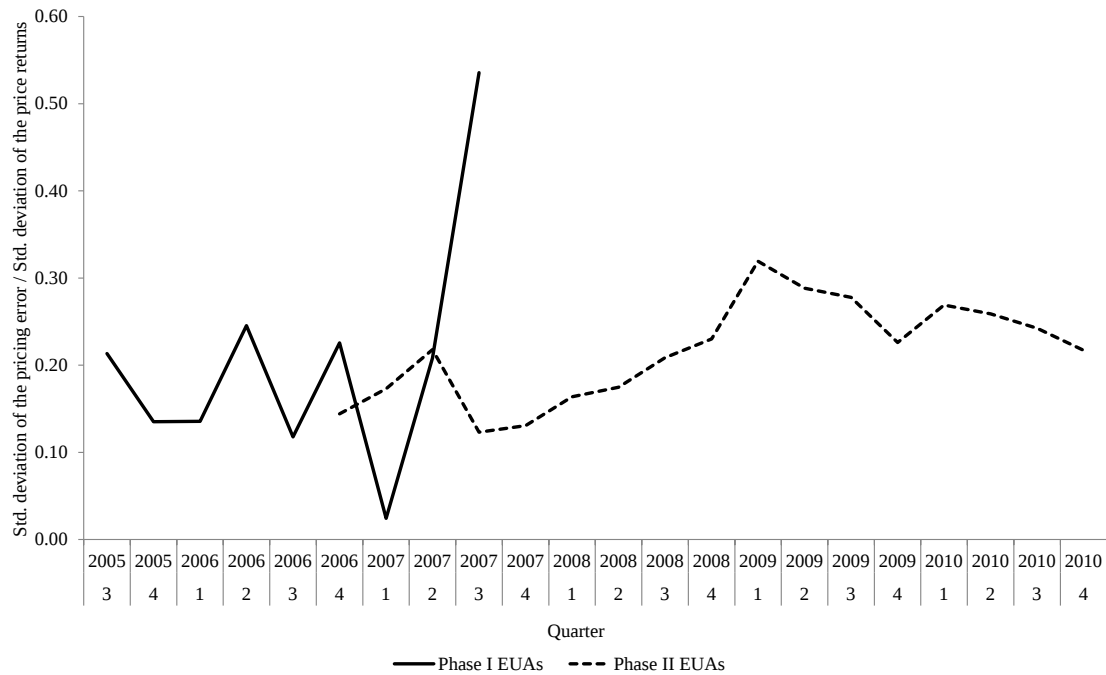
Comparing the trial phase for Phase I EUAs before the 2007 market collapse with the commitment phase for Phase II EUAs, we find that, in median terms, the role played by frictions in total volatility increased about 14% (p-value 0.0134), 18% if we look only to real frictions (p-value 0.0104). As a result, 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 the trial phase for Phase II EUAs with the commitment phase, 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 $Var(\Delta p_t)$ 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 $\{r_t, x_t, x_t^s, x_t^{s1/2}\}$, 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 the commitment phase 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 the trial phase showed higher quality levels than during the commitment phase (-9.19%, p-value 0.0061).

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.



6. Summary and conclusions

We have studied the history of trading frictions and market quality of the European carbon market. Two overlapping major events, the market collapse at the end of the trial phase, in 2007, and the irruption of the current international financial crisis during the commitment phase, 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 the trial phase (or Phase I), from 2005 to 2007, and the commitment phase (or Phase II), from 2008 to 2010. 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), hereafter MRR, 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 the trial phase (0.0675€) than during the commitment phase (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 the trial phase.

Regarding adverse selection costs (ASC), they represented 65% of the bid-ask spread (0.088€) at the start of the trial phase, but only 17.5% (0.0017€) by the end of 2007. During the commitment phase, 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 the trial phase to 0.03% towards the end of the commitment phase. 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 the trial and the commitment phases, 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 the trial phase than during the commitment phase. 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 the commitment phase, 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 the commitment phase. 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 marked 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 deteriorate. 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 the trial phase to the commitment phase. Even though the commitment phase 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 the trial phase (before the market collapse), friction-related volatility contribution to total volatility has been above ordinary Phase I levels. Our findings 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 on the real economy expectations. By the end of 2010, this recovery process has not finished yet.

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