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Stylized Facts of CO₂ Returns*

Vicente Medina and Ángel Pardo**

Abstract

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

Keywords: European Union Allowances (EUAs), Stylized Fact, Asset Class, Commodity.

JEL classification: G1.

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1. INTRODUCTION

In order to achieve the reduction objectives for greenhouse gases emissions, the European Union decided that a big part of that reduction would have to be directly assumed by the companies of the most polluting sectors. Since 2005, the companies of these sectors, included in the 2003/87/CE Directive, receive each year entitlements to emit one tonne of carbon dioxide equivalent gas, which are denominated European Union Allowances (EUAs).¹ At the end of the control period, the firms covered by the environmental regulations have to give a sufficient number of allowances to cover their verified real emissions. If these companies emit more CO₂ than the allowances they own, they would have to go to the European Union Emission Trading Scheme (EU ETS) and buy the difference. It is important to highlight that not only the polluting companies participate in the EU ETS, but also external agents can trade in it. Therefore, knowledge of the statistical properties of EUAs is of interest not only for hedging operations, but also for speculative or risk management purposes.

In spite of the youth of the EU ETS, the academic literature has analyzed the CO₂ market from diverse perspectives. Mansanet-Bataller and Pardo (2008) study the market at an institutional level. Miclus et al. (2008), Daskalakis and Markellos (2008), Daskalakis et al. (2009) and Mansanet-Bataller and Pardo (2009) study different aspects of the market efficiency. Benz and Hengelbrock (2008), Rotfuss (2009), Rittler (2012) and Uhrig-Homburg and Wagner (2009) analyzed the lead-lag relationship between the spot and futures markets, this last one being the market that leads the price discovery process. Finally, Borak et al. (2006), Chesney and Taschini (2011), Benz and Trück (2009) and Daskalakis et al. (2009) proposed different alternatives to model the price dynamics of CO₂ emission allowances.²

The papers mentioned above analyze short periods of time and the statistical properties of EUA returns appear as a secondary objective. This is precisely the main purpose of our study. Specifically, starting from the stylized facts described by Cont (2001) for financial assets, and from the statistical properties analyzed by Gorton and Rouwenhorst (2006) and Gorton et al. (2012) for commodities, we study the stylized empirical facts of EUA returns. By doing so, we will determine whether EUA behaves like a financial asset, a commodity, or a new asset. The knowledge of its statistical properties is of interest for both policy makers and portfolio managers, in terms of regulation and portfolio diversification, respectively. The remainder of the paper is organized as

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

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

follows. Section 2 presents the stylized facts observed in assets grouped into four categories. Section 3 describes the data we used in the study. The results of the analysis are presented and discussed in section 4. The last section summarizes with some concluding remarks.

2. STYLIZED FACTS OF ASSET RETURNS

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

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

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

returns. However, the majority of economic and financial time series exhibit trending behavior or non-stationarity in the mean. If EUA price series were non-stationary, any shock to EUA price would be permanent, implying that EUA future returns would be unpredictable based on historical observations.

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

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

The last group alludes to specific features extracted from commodities behaviors. The first aspect we investigate is the presence of a non-trading effect observed in the volatility of weather sensitive assets. Following Fleming et al. (2006), trading versus non-trading period variance ratios in weather-sensitive markets are lower than those in

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

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

3. DATA

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

Related to the time frame used in this study, it is convenient to clarify some aspects of the EU ETS. The trading on EUAs has been organized into different phases. Phase I covered the years from 2005 to 2007 and was considered as a *pilot* or *learning* phase, characterized by an excess of EUAs that provoked a sharp decline in prices.⁶ Phase II matches the Kyoto protocol fulfillment period which goes from January 2008 to December 2012, while Phase III will include the period 2013 to 2020.⁷ Another

⁵ The unit of trading of one contract is one lot of 1,000 CO₂ EU Allowances. See the User Guide of ICE ECX Contracts: EUAs and CERs at the <https://www.theice.com/productguide/ProductGroupHierarchy.shtml?groupDetail=&group.groupId=19> for further information about the contract specifications of ECX EUA futures contract (last accessed on March 20, 2012).

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

⁷ Given that the EU ETS is organized in Phases, the Member States must elaborate a National Allocation Plan (NAP) for the first two Phases, in which the Member States attribute their emission allowances to the different companies, included in the sectors involved in the 2003/87/CE Directive, and establish the emission limits for the different sectors, as well as for each one of the facilities covered by EU ETS.

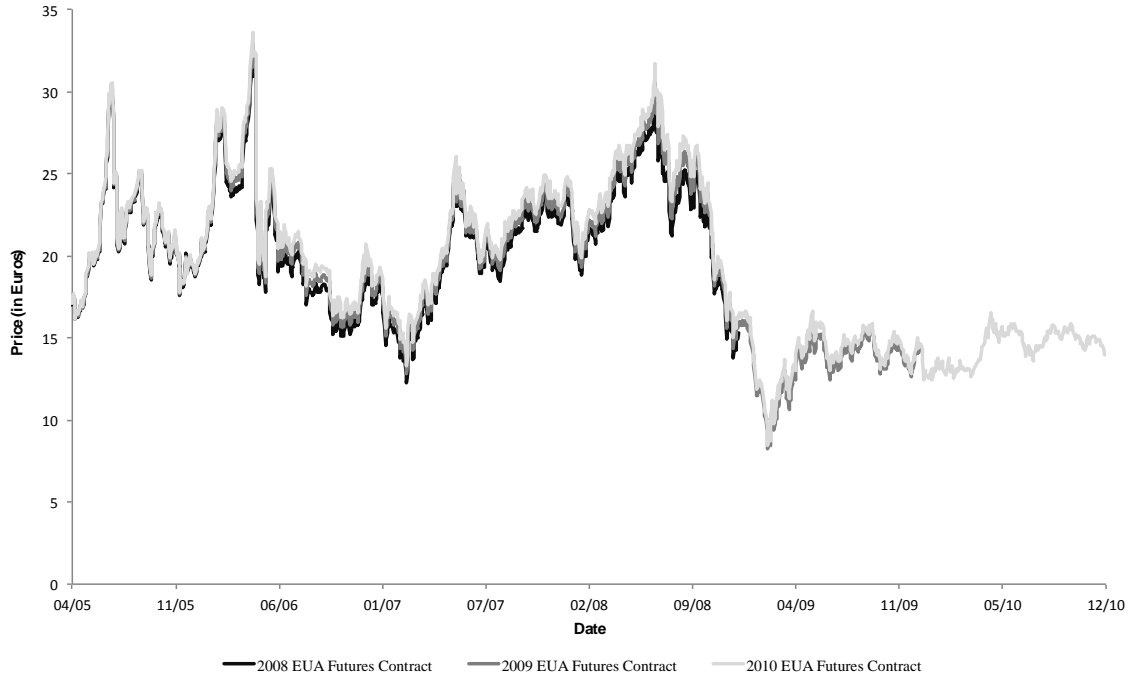
important aspect to consider is that Phase I EUAs could not be used in Phase II, meaning that *banking* was not allowed between Phase I and Phase II. Nevertheless, banking is allowed between Phase II and Phase III, a reason why Phase II EUAs might be used during the 2013 to 2020 period. For these reasons, we limit our sample to Phase II EUA futures returns. In particular, we focus on 2008, 2009 and 2010 EUA ECX futures contracts. The period sample goes from April 22, 2005 to December 15, 2008 for the first contract; from April 22, 2005 to December 14, 2009 for the second one, and from April 22, 2005 to December 20, 2010 for the third one, collecting 936, 1,190 and 1,446 daily returns for 2008, 2009 and 2010 EUA ECX futures contracts, respectively. Figure 1 shows the price evolution for the three EUA futures contracts. In general, all three contracts share a common behavior. Until April 24, 2006, future prices had a positive trend, over-passing the 30 Euros price per contract, but continuous rumours of over-allocation crashed Phase I prices, affecting negatively Phase II prices too. From then, prices declined until it reached its first minimum of 14 Euros in February 2007. In July 2008, EUA prices approached their maximum quote of over 30 Euros, following which prices started a new bearish period because of the financial crisis. By February 2009, EUA prices reached their historical minimum around 8 Euros. Finally, from April 2009 to the end of 2010, EUA prices have been fluctuating around 14 Euros.

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

Therefore, these NAPs establish the EUA supply available in the market until 2012. Contrary to Phase I and Phase II, in Phase III, only one EU-wide emissions allocation under ETS Phase III will be elaborated, where each installation's individual allocation will be decided by the European Commission.

Figure 1. Prices evolution

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



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

4. RESULTS

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

4.1. Data distribution

From a financial point of view, the *gaussianity* of returns data is of interest for portfolio theory, derivatives pricing and risk management. However, one of the most well-known properties in the distributions of assets returns is precisely the non-normality of the return series and the fact that they present a greater number of extreme values than those

observed in series with Gaussian distributions.⁸ As a background, Table I presents the summary statistics of the EUA returns for 2008, 2009 and 2010 futures contracts, and Figures 2a, 2b and 2c show the histogram of the historical daily return distribution. All three daily series are leptokurtic and present negative skewness. The Jarque-Bera statistic rejects the null hypothesis of normality for all three series at the 5% level. The histogram shows heavy tails and a high number of extreme returns, both positive and negative ones.

Table I. Summary statistics for EUA futures returns

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

Panel A: 2008 EUA Futures Contract						
	Daily	Monday to Monday	Wednesday to Wednesday	Monthly Based day 1	Monthly Based day 15	Residuals EGARCH
Mean	-0.0001	-0.0007	-0.0007	-0.0011	-0.0025	-0.0140
Median	0.0013	0.0072	0.0033	-0.0026	0.0022	0.0209
Maximum	0.1865	0.2076	0.1441	0.3189	0.2786	3.9433
Minimum	-0.2882	-0.5146	-0.3757	-0.3780	-0.3405	-7.5034
Std. Dev.	0.0286	0.0767	0.0646	0.1532	0.1317	1.0003
Skewness	-1.3166	-1.8022	-1.3332	-0.2364	-0.2879	-0.5897
Kurtosis	17.9459	13.1149	9.5885	2.7371	3.0530	7.6354
Jarque-Bera	8,982.2510	912.8140	397.8340	0.5240	0.5990	891.3000
p-value	0.0000	0.0000	0.0000	0.7690	0.7410	0.0000
K-S stat	2.9130	1.2370	1.1710	0.5710	0.5210	2.6360
p-value	0.0000	0.0940	0.1280	0.9000	0.9490	0.0000
Observations	936	190	189	43	43	935

Panel B: 2009 EUA Futures Contract						
	Daily	Monday to Monday	Wednesday to Wednesday	Monthly Based day 1	Monthly Based day 14	Residuals EGARCH
Mean	-0.0001	-0.0009	-0.0006	-0.0035	-0.0031	-0.0085
Median	0.0007	0.0050	0.0032	-0.0013	0.0132	0.0283
Maximum	0.1932	0.2069	0.1782	0.3219	0.4039	3.6552
Minimum	-0.2811	-0.5087	-0.3667	-0.3697	-0.4580	-7.8527
Std. Dev.	0.0286	0.0757	0.0649	0.1498	0.1487	1.0003
Skewness	-0.8873	-1.4620	-1.0739	-0.2569	-0.3153	-0.5654
Kurtosis	14.4420	10.9417	8.0011	2.7422	4.1379	7.1086
Jarque-Bera	6,647.5940	722.1760	2.9740	0.7570	3.8780	899.6650
p-value	0.0000	0.0000	0.0000	0.6850	0.1440	0.0000
K-S stat	2.9180	1.2680	1.3740	0.6240	0.6300	2.9260
p-value	0.0000	0.0800	0.0460	0.8310	0.8220	0.0000
Observations	1,190	242	241	55	55	1,189

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

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

Panel C: 2010 EUA Futures Contract						
	Daily	Monday to Monday	Wednesday to Wednesday	Monthly Based day 1	Monthly Based day 20	Residuals EGARCH
Mean	-0.0001	-0.0008	-0.0005	-0.0015	-0.0030	-0.0003
Median	0.0002	0.0019	0.0018	-0.0020	-0.0020	0.0005
Maximum	0.1912	0.2078	0.1830	0.3249	0.2801	0.1979
Minimum	-0.2743	-0.5016	-0.3582	-0.3654	-0.3710	-0.2711
Std. Dev.	0.0268	0.0708	0.0597	0.1392	0.1254	0.0267
Skewness	-0.8500	-1.4094	-1.0625	-0.2087	-0.2978	-0.8110
Kurtosis	14.5575	11.3714	8.6198	3.1254	3.5760	14.4896
Jarque-Bera	8,222.0183	959.0620	442.2060	0.5304	1.9451	8,106.6428
p-value	0.0000	0.0000	0.0000	0.7670	0.3781	0.0000
K-S stat	3.0339	1.5029	1.7856	0.4845	0.5570	3.0453
p-value	0.0000	0.0218	0.0034	0.9730	0.9157	0.0000
Observations	1,446	295	294	67	68	1,445

Figure 2. Returns histograms

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

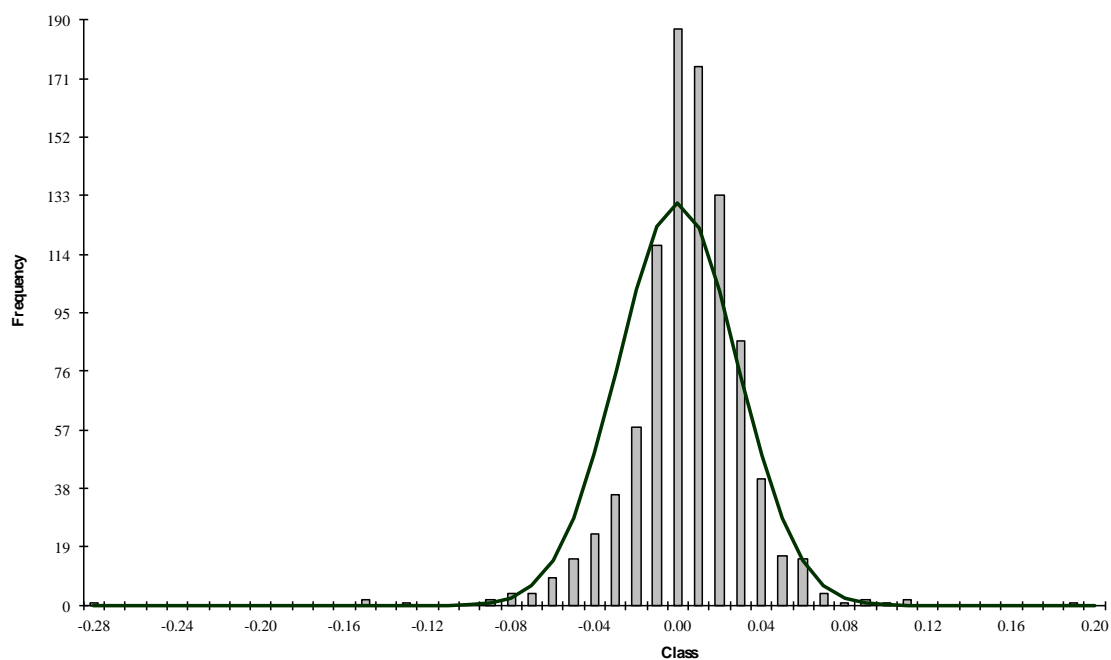


Figure 2a. 2008 EUA Futures Contract

Figure 2. Returns histograms (continue)

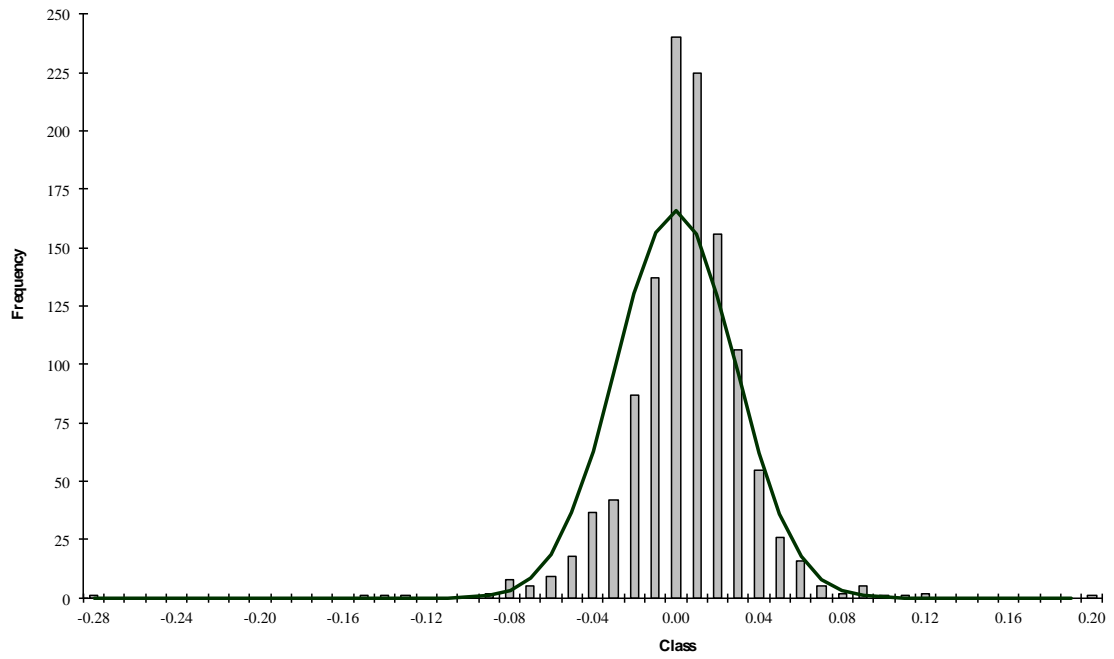


Figure 2b. 2009 EUA Futures Contract

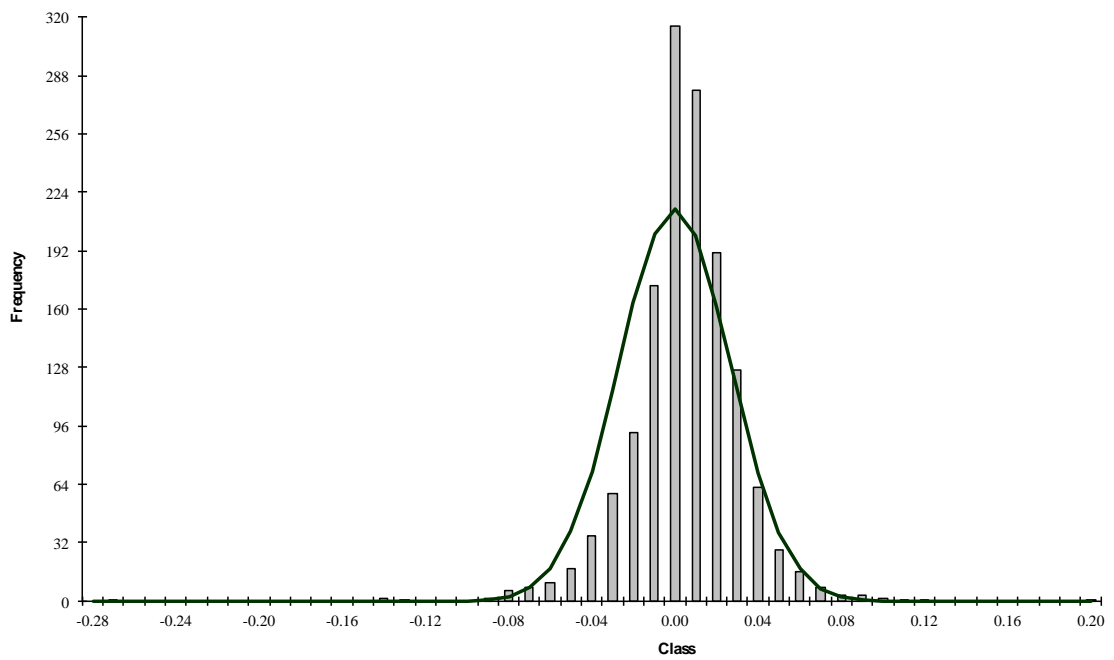


Figure 2c. 2010 EUA Futures Contract

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

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

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

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

Table II. Outlier detection

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

Panel A: Outliers summary

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

Panel B: Size of Outliers (σ s)

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

Panel C: Clusters of Outliers

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

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

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

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

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

returns calculating returns from two consecutive mid-months days, for all three futures contracts. We obtain similar results, presented in Table I, that confirm the fact that the empirical distribution of EUA returns tends to normality as the frequency of observation decreases.

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

Table III. Unit root tests

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

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

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

4.2. Correlation facts

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

Table IV. Autocorrelation tests

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

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

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

Finally, we analyze the presence of a slow decay of autocorrelation in absolute returns, also known as the *Taylor effect*, which would indicate that large returns in absolute terms are more probably followed by another large return, rather than a small one. Note that we have already obtained preliminary evidence of dependence among outliers;

however, the *Taylor effect* makes reference to a feature that is present in the entire sample. To test this effect, we have obtained the Spearman's ranks autocorrelation coefficient taking into account absolute returns. Table VI presents the results that indicate a significant slow decay of sample autocorrelation coefficients at the 5% level, suggesting a long-range dependence in absolute returns.

Table V. Run tests

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

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

Table VI. Taylor effect

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

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

4.3. Volatility-related features

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

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

Figure 3. Volatility clustering

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

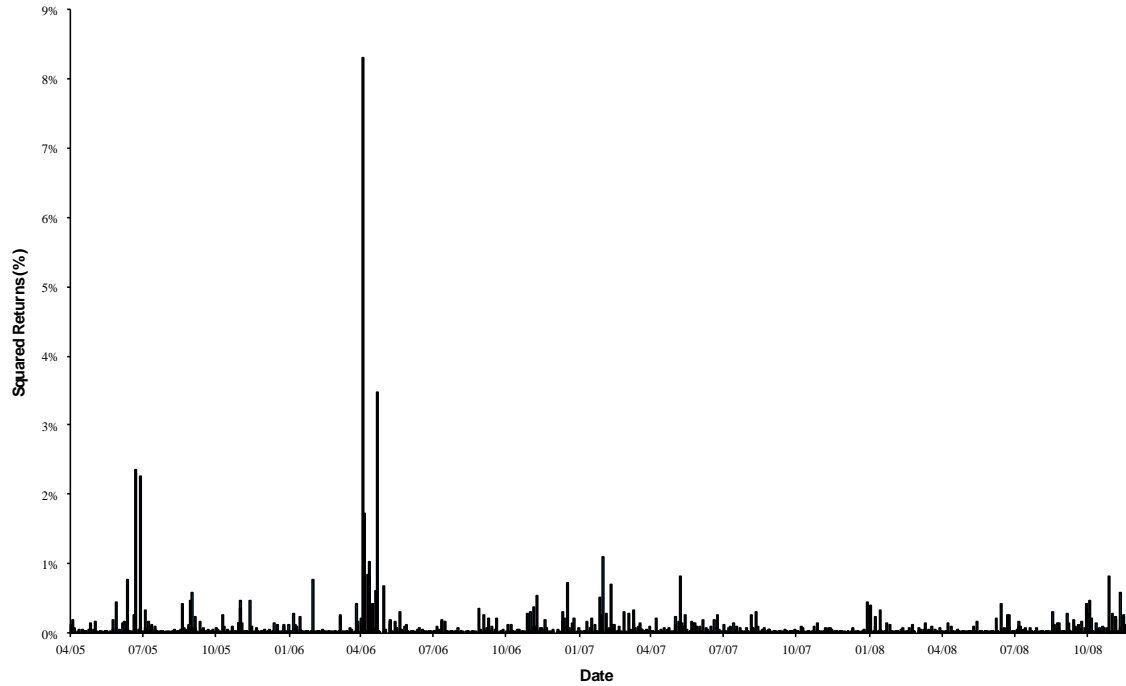


Figure 3a. Squared returns representation for 2008 EUA Futures Contract

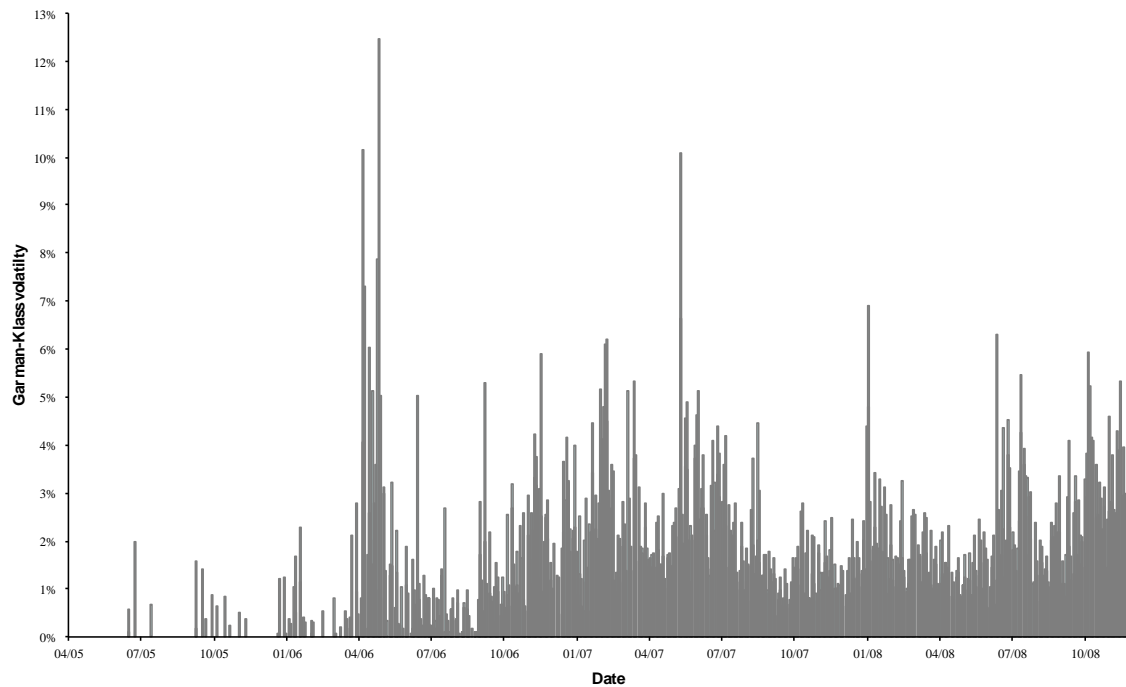


Figure 3b. Garman-Klass volatility for 2008 EUA Futures Contract

Figure 3. Volatility clustering (continue)

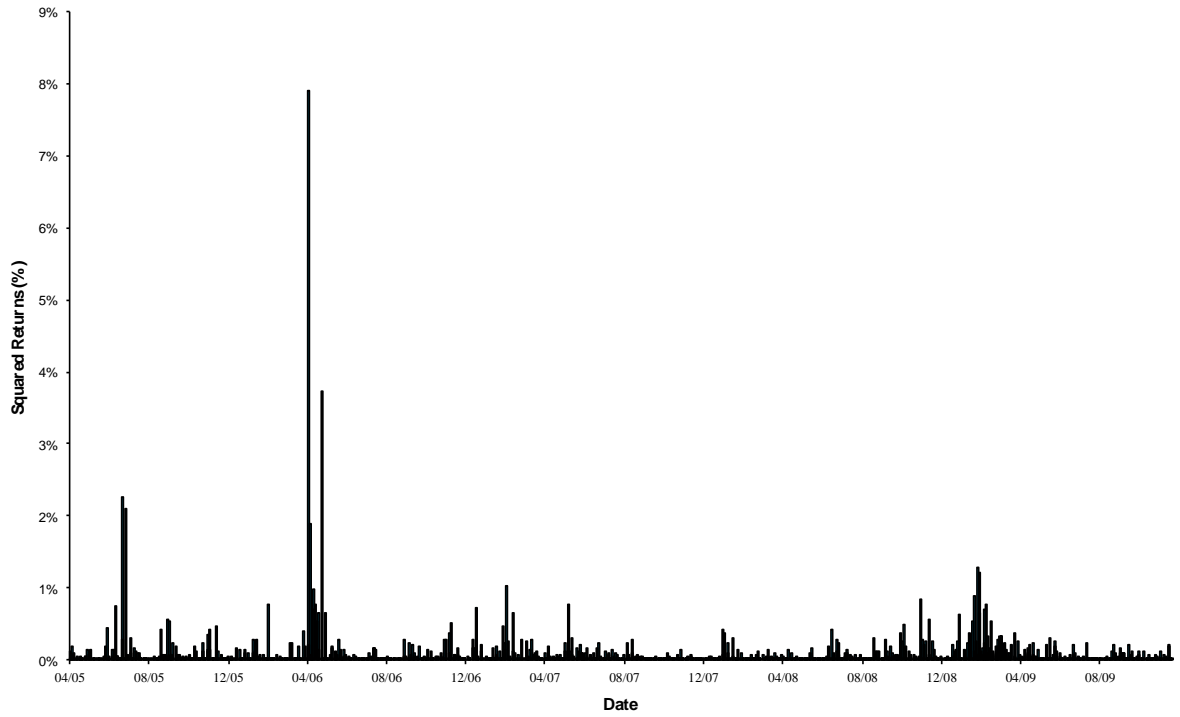


Figure 3c. Squared returns representation for 2009 EUA Futures Contract

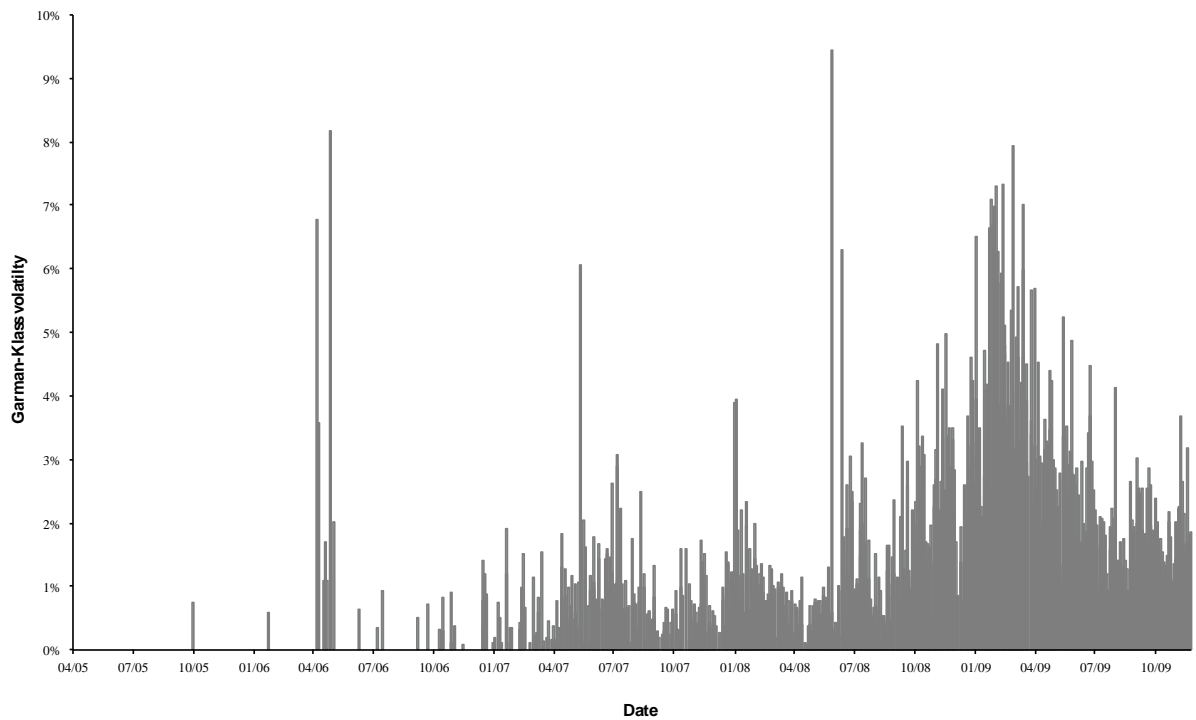


Figure 3d. Garman-Klass volatility for 2009 EUA Futures Contract

Figure 3. Volatility clustering (continue)

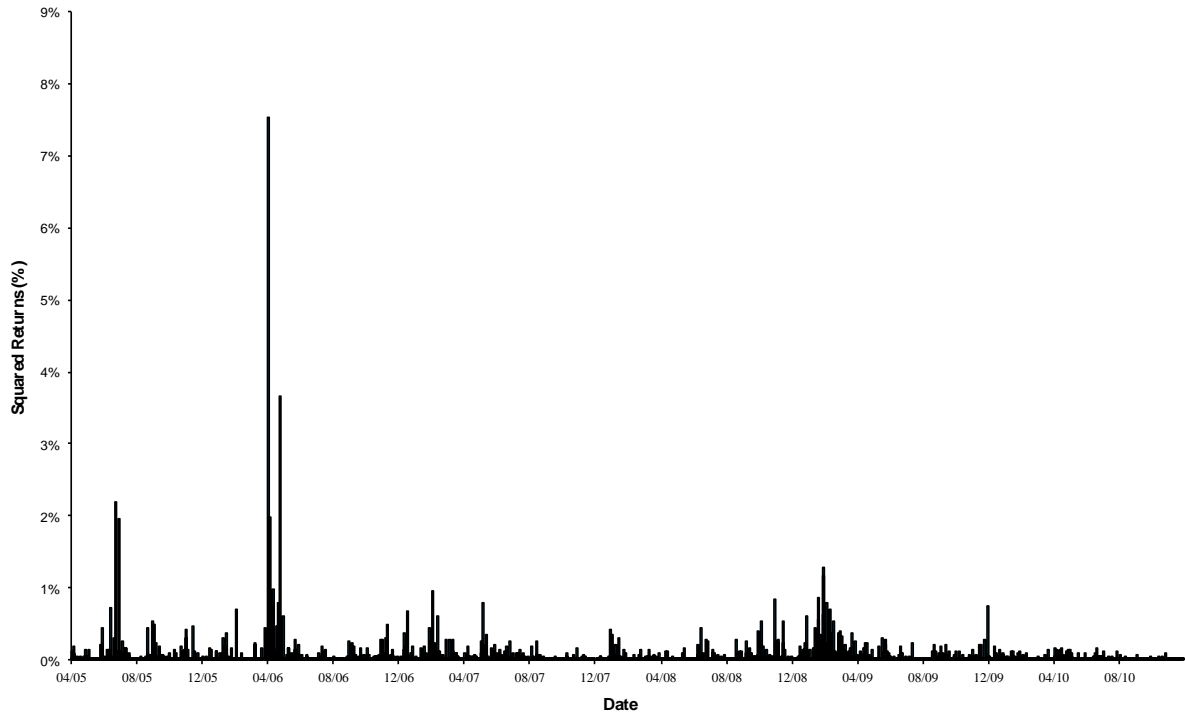


Figure 3e. Squared returns representation for 2010 EUA Futures Contract

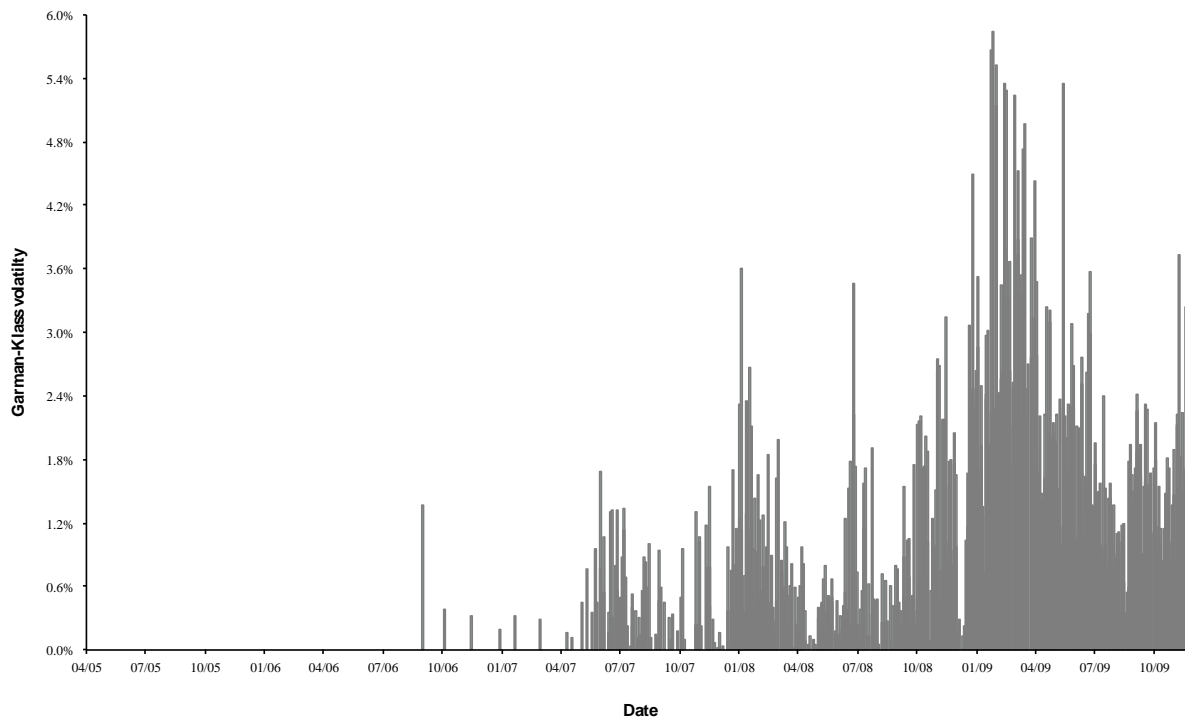


Figure 3f. Garman-Klass volatility for 2010 EUA Futures Contract

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

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

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

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

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

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

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

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

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

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

Table VII. Volatility-related features

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

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

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

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

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

Table VIII. Trading-related features

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

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

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

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

4.4. *Commodity features*

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

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

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

non-trading hours, our results clearly indicate that information flow is concentrated during the business day, similar to the equity markets, and does not evolve randomly around the clock.

Table IX. Information flows

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

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

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

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

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

Table X. Correlation with bonds, stocks and Brent

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

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

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

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

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

Euribor rate as a proxy, leaving the non-expected inflation as the difference between the observed and the expected inflation.

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

Table XI. Inflation hedge

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

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

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

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

5. CONCLUSIONS

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

We have found evidence of intermittency, *aggregational gaussianity*, short-term predictability, Taylor effect, volatility clustering, asymmetric volatility, and positive relation between volatility and volume and between the volatility and the change in the open interest. Our findings suggest that temporal dependences should be modeled with ARMA-GARCH structures. However, the persistence of conditional heavy-tails indicates that in order to capture the volatility features of EUA return data; fat-tailed

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

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