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Volatility Transmission in the CO_2 and Energy Markets

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Abstract

The main consequence of the launch, in 2005, of the European Union Emission Trading Scheme (EU ETS) has been the establishment of a price for carbon emissions. Thus, major energy producers in Europe are now aware of the impact of their polluting activities. The interest in analysing the carbon markets from a financial point of view has exponentially increased since the launch of the EU ETS. However, no research articles have focused their attention on the volatility transmission between CO_2 and energy markets. The aim of this paper is to fill this gap in the literature. Specifically, our particular interest is to examine whether or not conditional volatility is transmitted across those markets since the start the EU ETS. We consider not only non-linearity in the variance of each series but we also allow for the possibility that changes in volatility in one of the markets may spill over to the others. The results show that CO_2 is directly affected by its own volatility, and directly and indirectly (through the covariance) affected by the oil and natural gas volatility. Additionally, shocks originated in the CO_2 and oil markets have an impact on CO_2 volatility. Finally, the behaviour of oil volatility is similar to CO_2 volatility in what concerns volatility transmission but this is not the case for natural gas volatility.

Keywords: CO_2 Futures, Energy Markets, and Market Volatility.

JEL codes: C10, C32, G15, Q49.

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1. Introduction

The main consequence of the launch, in January 2005, of the European Union Emission Trading Scheme (EU ETS) has been the establishment of a price for carbon emissions. Thus, major energy producers in Europe, and specifically the installations under the 2003/87/EC directive, are now aware of the impact of their polluting activities. As Stern (2006) pointed out, this is one of the first steps in order to deal with Climate Change and we may say that this has been one of the principal contributions of Phase I of the EU ETS.

As it is well known, the EU ETS is organised in two Phases. Phase I may be considered as a pilot phase and it run from the 1st January 2005 to the 31st December 2007. On the other hand, Phase II started the 1st January 2008 and will run until 31st December 2012. Thus, this second phase coincides with the Kyoto protocol commitment period. Note that the European Commission has already confirmed that the European Union will continue with the EU ETS after 2012 even in the case that no international agreement is taken in the COP-15 in Copenhagen, in December 2009. So Phase III of the EU ETS will start the 1st January 2013 and will probably last until the 31st December 2020.[1]

Since the start of the EU ETS, the interest in studying the carbon markets from a financial point of view has exponentially increased. For example, Uhrig and Wagner (2007) analysed the relationship between spot and futures prices in the EU ETS. Their empirical evidence suggests that after December 2005 spot and futures prices were linked by the cost-of-carry approach. In Alberola and Chevalier (forthcoming) the focus is in the study of the intra-period banking during Phase I and the effects of inter-period banking restrictions between phases I and II of the EU ETS. Additionally, several articles such as Mansanet-Bataller et al. (2007) and Alberola et al. (2008) have focused their attention on the determinants of CO_2 prices. They provided evidence that lagged energy prices (Brent and natural gas) as well as weather variables may explain CO_2 prices for the first period of the EU ETS (2005-2007).

Our start point is that if energy returns do have an impact on CO_2 returns, it could also be the case of energy volatility having an impact on CO_2 volatility. In fact, it seems that some markets have even more interdependence in volatility than in returns. However, no research articles have focused on the volatility transmission between CO_2 and energy markets. The aim of this paper is to fill this gap in the literature.

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[1] Please see Ellerman and Buchner (2007) and Mansanet-Bataller and Pardo (2008) for a detailed description of the EU ETS.

Given that Phase I is already finished, that it was not possible to bank allowances from Phase I to Phase II (period from 2008-2012), and that Phase II prices have been traded since the beginning of the EU ETS, we focus our attention on EU ETS Phase II prices. Specifically, our particular interest is to examine whether or not conditional volatility is transmitted across CO_2 and energy markets. We consider not only non-linearity in the variance of each series but we also allow for the possibility that changes in volatility in one of the markets may spill over to the others.

Nowadays, several financial assets are traded in the market based on CO_2 and energy markets. Specifically, note that options on CO_2 futures contracts are traded since the 13th October 2006. Therefore, it is important to analyse the volatility transmission patterns across these markets to facilitate optimal portfolio allocation and risk management decisions. In fact, volatility becomes a key variable both when it is interpreted as a proxy for information flow and when used for valuation of options and other derivatives.

There are some studies, such as Estrada and Fugleberg (1989), Serletis and Herbert (1999), and Soderholm (2000), that analyse price spillover effects between the oil and natural gas markets, but they ignore the possibility of volatility spillovers. Ewing et al. (2002), analyses volatility transmission between these markets and we extend their work by analysing the relationship between CO_2 and energy markets.

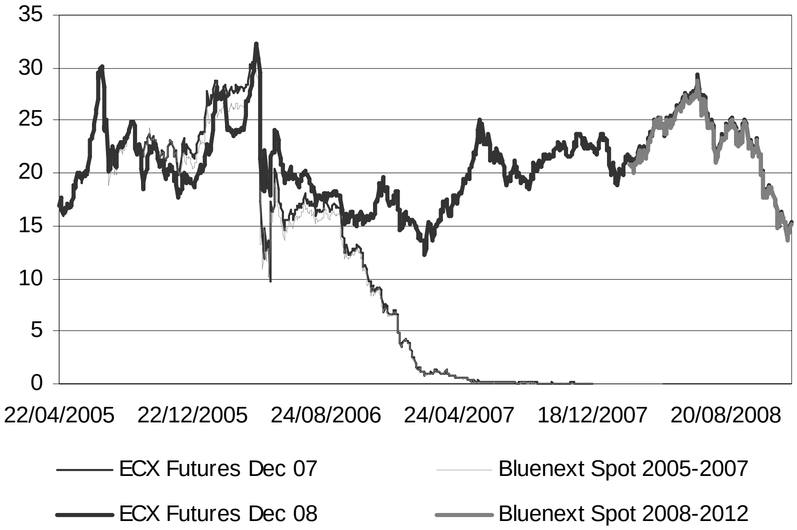
The rest of the paper is organised as follows. Section 2 describes the data and offers some preliminary analysis, section 3 deals with the methodology, section 4 presents the empirical results and section 5 summarises and makes some concluding remarks.

2. Data

There are several organised markets in Europe where it is possible to trade European Union Allowances (the tradable right to emit a tonne of CO_2 in the European Union) through a wide variety of contracts. However, note that only contracts of European Union Allowances (EUAs) for the first two phases of the EU ETS have been traded since its beginning.

As pointed out by Mansanet-Bataller and Pardo (2008), all prices corresponding to the same phase were highly correlated independently of which trading platform and type of contract we considered. In Figure 1 we consider the most representative prices for the spot and futures contracts for each one of the phases. That is Bluenext prices for the spot market and European Climate Exchange (ECX) December 2007 and December 2008 futures contract prices.

Figure 1: EUA Phase I and Phase II price evolution



Sources: BlueNext and ECX web pages.

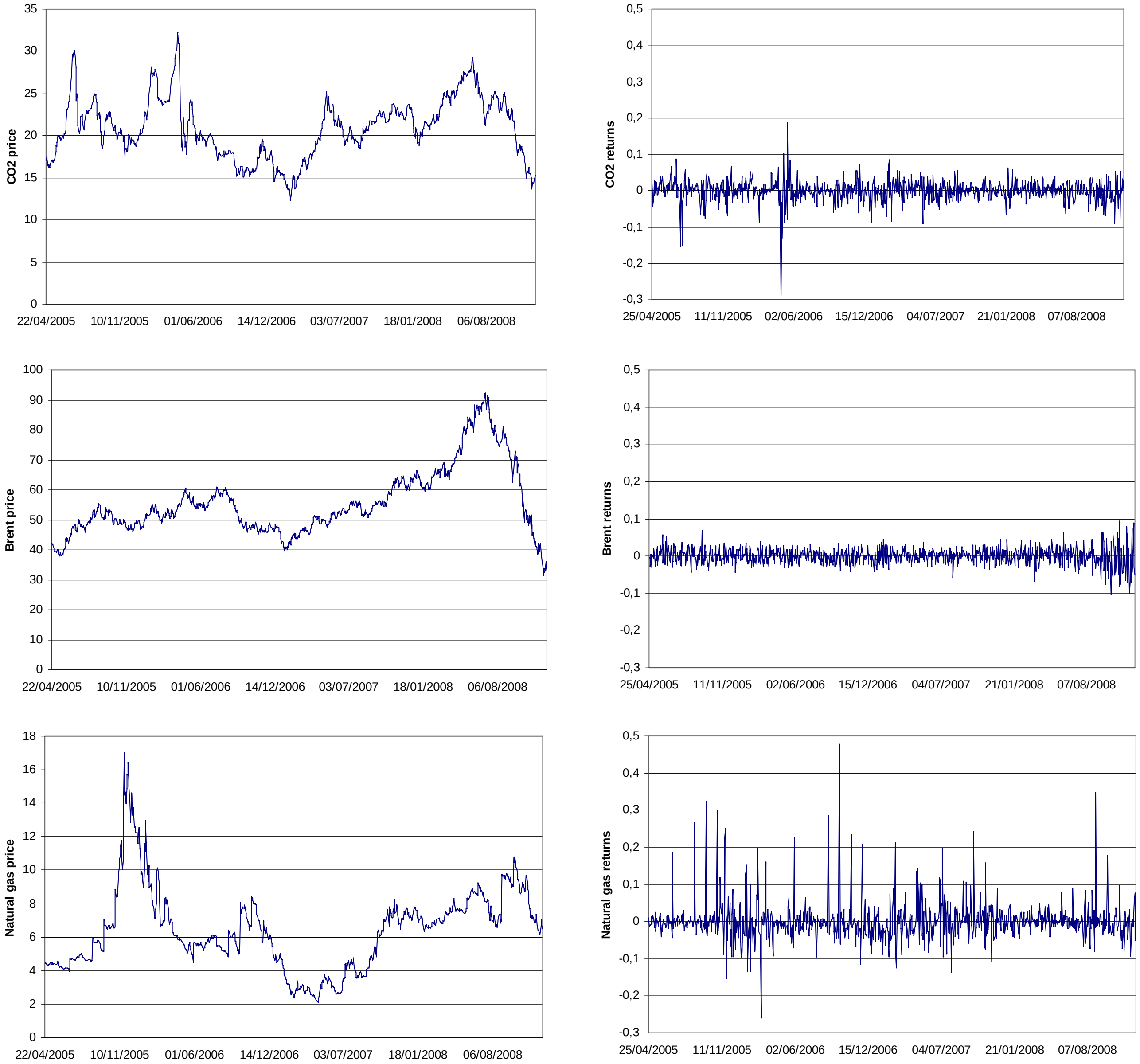
Even if the prices for Phase I and Phase II started by presenting a very high correlation, at the end of year 2006 Phase I prices came to zero while Phase II prices continued to be traded at levels around 20 euros. The reason of the huge decrease in Phase I prices was the confirmation that the allowances distributed by the Member States were superior to the real emissions of the sectors covered by the EU ETS. As banking was not allowed between the two phases of the EU ETS, Phase I and Phase II EUAs were two differentiated assets and thus, Phase II EUA prices followed a pattern completely different than those of Phase I.

In order to analyse volatility transmission between CO_2 and energy prices we have considered the most representative CO_2 prices for Phase II of the EU ETS. That is, we have considered the futures contract traded at the ECX with delivery December 2008, for the period April 2005-December 2008. There are several reasons that justify such a choice: (i) the drop of EUA Phase I prices at the end of 2006 to levels close to zero reduces the interest of studying Phase I volatility transmission, (ii) futures contracts for EUA Phase II started to be traded at the same time as futures contracts for Phase I, (iii) Phase I only took three years and it is already finished and, finally, (iv) there will be banking between Phase II and Phase III of the EU ETS and thus the continuity of the Phase II price series is guaranteed.

In what concerns energy prices, we have considered the most representative prices of oil (Brent) and natural gas in Europe. That is the monthly front contract of those commodities traded at the Intercontinental Exchange Futures (ICE Futures). The reason for such a choice is principally that there are some empirical papers, Alberola and Chevalier (forthcoming) and Mansanet-Bataller et al. (2007), that find evidence on the relationship between those energy variables returns and CO_2 returns. Therefore, we may think that volatility in those energy variables may have an impact on volatility of CO_2 prices.

All price series present a unit root and they have been converted into stationary by taking first natural logarithm differences. Figure 2 displays the daily evolution (in prices and returns) of the CO_2, Brent and natural gas prices considered, in the analysed period.

Figure 2: Daily Evolution of CO_2, Brent and Natural Gas Prices and Returns



Sources: Reuters and ECX web page.

Table 1 presents some summary statistics on the daily returns. The Jarque-Bera tests reject normality of the returns for the three commodities, basically due to the excess of kurtosis. The Ljung-Box test indicates significant autocorrelation in the CO_2 and oil markets but not in the natural gas market.

Table 1: Descriptive Statistics

	CO_2 returns	Oil returns	Natural gas returns
Mean	-0.0113	-0.0259	0.0401
Standard Dev.	2.8698	2.2015	5.1562
Skewness	-1.3176	-0.2231	2.6805
Kurtosis	17.7379	5.2263	20.5405
Jarque-Bera	7676.181	200.4361	13077.97
	(0.000)	(0.000)	(0.000)
Q(12)	30.339	55.258	12.000
	(0.002)	(0.000)	(0.446)

P-values displayed as (.). The Jarque-Bera statistic tests for the normal distribution hypothesis. Q(12) is the Ljung-Box tests for twelfth order serial correlation.

3. Methodology

The econometric model used to analyse interrelations between Phase II EUA futures prices, Brent and natural gas markets has two parts: the mean equation and the variance-covariance equation.

Equation (1) models the returns in the CO_2, Brent and natural gas markets as a first order Vector Autoregressive VAR(1) process. Lag order selection is based on the AIC criterion. Using matrix algebra:

$$\begin{bmatrix} R_{1,t} \\ R_{2,t} \\ R_{3,t} \end{bmatrix} = \begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \end{bmatrix} + \begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix} \begin{bmatrix} R_{1,t-1} \\ R_{2,t-1} \\ R_{3,t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \varepsilon_{3,t} \end{bmatrix} \qquad (1)$$

where Rt is the vector of daily returns in the three markets at time t, μ is a vector of constants, εt is a vector of innovations and D is a 3x3 matrix of parameters.

Equation (1) describes the returns of the CO_2 (R1,t), oil (R2,t) and natural gas (R3,t) markets as a VAR(1) process where the conditional mean in each market is a function of a constant, past own returns and the other two markets' past returns. The coefficients in D measure those own and cross-effects. From the mean equation we get the residuals that will be used as input in the variance-covariance equation.

Past evidence Ewing et al. (2002) indicates that commodity returns exhibit ARCH effects and that energy markets could be related both at the mean and the variance level. It is reasonable to assume that the same characteristics could hold for CO_2 data. We therefore employ a Generalised Autorregressive Conditional Heteroskedasticity (GARCH) model to analyse volatility transmission patterns between CO_2 and energy markets.

As we are interested in the interrelationship between different commodity markets, a multivariate GARCH framework is necessary. Different multivariate GARCH specifications have been proposed in the literature. The four multivariate GARCH models mostly used in the literature are the VECH, Diagonal, Constant Conditional Correlation (CCC) and BEKK models. Each one of them imposes different restrictions in the conditional variance. In the VECH model Bollersev et al. (1988), certain restrictions must be accomplished in order to assure a positive definite variance-covariance matrix. The Diagonal representation Bollersev et al. (1988), reduces the number of parameters to be estimated, but it also removes the potential interactions in the variances of different markets. Bollerslev (1990) proposes a model with constant correlations between markets. However, different studies (see Longin and Solnik (1995)) have shown that this assumption is violated in some markets. Finally, the BEKK model Engle and Kroner (1995) is the specification that best fits our objectives. The main advantage of this specification is that it reduces significantly the number of parameters to be estimated without imposing strong constraints on the shape of the interaction between markets. Moreover, it guarantees that the variance-covariance matrix will be positive definite.

Therefore, our variance-covariance matrix will follow the BEKK model proposed by Engle and Kroner (1995). The whole compacted model is written as follows:

$$H_t = C'C + B'H_{t-1}B + A'\varepsilon_{t-1}\varepsilon_{t-1}^{'}A \tag{2}$$

where C, B, and A are 3x3 matrices of parameters, being C upper triangular. Ht is the 3x3 conditional variance-covariance matrix and εt is a 3x1 vector containing the unexpected shocks obtained from equation (1). This BEKK specification requires estimation of 24 parameters.

The B matrix depicts the extent to which current levels of conditional variances are related to past conditional variances. Similarly, the elements in A capture the effects of lagged shocks or events on current volatility.

The conditional variance for each equation can be expanded for the trivariate BEKK as follows:

$$\begin{aligned} h_{11,t} &= c_{11}^2 + b_{11}^2 h_{11,t-1} + b_{21}^2 h_{22,t-1} + b_{31}^2 h_{33,t-1} + 2b_{11}b_{21}h_{12,t-1} + 2b_{11}b_{31}h_{13,t-1} \\ &+ 2b_{21}b_{31}h_{23,t-1} + a_{11}^2\varepsilon_{1,t-1}^2 + a_{21}^2\varepsilon_{2,t-1}^2 + a_{31}^2\varepsilon_{3,t-1}^2 + 2a_{11}a_{21}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + \\ &+ 2a_{11}a_{31}\varepsilon_{1,t-1}\varepsilon_{3,t-1} + 2a_{21}a_{31}\varepsilon_{2,t-1}\varepsilon_{3,t-1} \end{aligned} \tag{3}$$

$$\begin{aligned} h_{22,t} &= c_{12}^2 + c_{22}^2 + b_{12}^2 h_{11,t-1} + b_{22}^2 h_{22,t-1} + b_{32}^2 h_{33,t-1} + 2b_{12}b_{22}h_{12,t-1} + 2b_{12}b_{32}h_{13,t-1} \\ &+ 2b_{22}b_{32}h_{23,t-1} + a_{12}^2\varepsilon_{1,t-1}^2 + a_{22}^2\varepsilon_{2,t-1}^2 + a_{32}^2\varepsilon_{3,t-1}^2 + 2a_{12}a_{22}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + \\ &+ 2a_{12}a_{32}\varepsilon_{1,t-1}\varepsilon_{3,t-1} + 2a_{22}a_{32}\varepsilon_{2,t-1}\varepsilon_{3,t-1} \end{aligned} \tag{4}$$

$$\begin{aligned} h_{33,t} &= c_{13}^2 + c_{23}^2 + c_{33}^2 + b_{13}^2 h_{11,t-1} + b_{23}^2 h_{22,t-1} + b_{33}^2 h_{33,t-1} + 2b_{13}b_{23}h_{12,t-1} \\ &+ 2b_{13}b_{33}h_{13,t-1} + 2b_{23}b_{33}h_{23,t-1} + a_{13}^2\varepsilon_{1,t-1}^2 + a_{23}^2\varepsilon_{2,t-1}^2 + a_{33}^2\varepsilon_{3,t-1}^2 + \\ &+ 2a_{13}a_{23}\varepsilon_{1,t-1}\varepsilon_{2,t-1} + 2a_{13}a_{33}\varepsilon_{1,t-1}\varepsilon_{3,t-1} + 2a_{23}a_{33}\varepsilon_{2,t-1}\varepsilon_{3,t-1} \end{aligned} \tag{5}$$

Equations (3), (4) and (5) reveal how shocks and volatility are transmitted over time and across markets. In the variance equations, the elements in C, B, and A can not be interpreted individually. Instead, we have to interpret the non-linear functions of the parameters which form the intercept terms and the coefficients of the lagged variances, covariances and error terms. We follow Kearney and Patton (2000) and calculate the expected value and the standard error of those non-linear functions. The expected value of a non-linear function of random variables is calculated as the function of the expected value of the variables, if the estimated variables are unbiased. In order to calculate the standard errors of the function, a first-order Taylor approximation is used. This linearizes the function by using the variance-covariance matrix of the parameters as well as the mean and standard error vectors.

4. Results

The results of estimating the GARCH model with BEKK parameterization for the variance equation of the three variables are presented in Table 2.

Table 2: Results of Multivariate BEKK Model

CO_2 conditional variance equation						
$h_{11,t} = 0.7208$	$+0.0055\, h_{11,t-1}$	$+0.3386\, h_{22,t-1}$	$+0.1046\, h_{33,t-1}$	$+0.0870\, h_{12,t-1}$	$+0.0483\, h_{13,t-1}$	$+0.3765\, h_{23,t-1}$
0.1058	0.0003	0.0125	0.0032	0.0032	0.0017	0.0090
(6.8086)	(15.376)	(26.967)	(32.262)	(26.714)	(27.760)	(41.381)
$+0.0648\, \varepsilon^2_{1,t-1}$	$+0.2442\, \varepsilon^2_{2,t-1}$	$+0.0002\, \varepsilon^2_{3,t-1}$	$+0.2518\, \varepsilon_{1,t-1}\varepsilon_{2,t-1}$	$-0.0087\, \varepsilon_{1,t-1}\varepsilon_{3,t-1}$	$-0.0170\, \varepsilon_{2,t-1}\varepsilon_{3,t-1}$	
0.0022	0.0117	0.0006	0.0074	0.0098	0.0191	
(28.621)	(20.831)	(0.4448)	(33.685)	(−0.8896)	(−0.8895)	
Oil conditional variance equation						
$h_{22,t} = 0.6493$	$+0.0130\, h_{11,t-1}$	$+0.5669\, h_{22,t-1}$	$+0.0221\, h_{33,t-1}$	$-0.1719\, h_{12,t-1}$	$+0.0340\, h_{13,t-1}$	$-0.2242\, h_{23,t-1}$
0.0610	0.0004	0.0131	0.0019	0.0036	0.0016	0.0103
(10.638)	(28.156)	(43.029)	(11.167)	(-47.121)	(20.761)	(−21.618)
$+0.0003\, \varepsilon^2_{1,t-1}$	$+0.0042\, \varepsilon^2_{2,t-1}$	$+0.0007\, \varepsilon^2_{3,t-1}$	$-0.0023\, \varepsilon_{1,t-1}\varepsilon_{2,t-1}$	$+0.0010\, \varepsilon_{1,t-1}\varepsilon_{3,t-1}$	$-0.0036\, \varepsilon_{2,t-1}\varepsilon_{3,t-1}$	
0.0012	0.0074	0.0007	0.0048	0.0019	0.0036	
(0.2764)	(0.5676)	(1.0012)	(-0.4971)	(0.5329)	(−0.9876)	
Natural gas conditional variance equation						
$h_{33,t} = 24.982$	$+0.0000\, h_{11,t-1}$	$+0.0675\, h_{22,t-1}$	$+0.0026\, h_{33,t-1}$	$+0.0001\, h_{12,t-1}$	$+0.0001\, h_{13,t-1}$	$+0.0266\, h_{23,t-1}$
0.5318	0.0000	0.0265	0.0033	0.0709	0.0139	0.0178
(46.971)	(0.0010)	(2.5472)	(0.7772)	(0.0021)	(0.0021)	(1.4868)
$+0.0038\, \varepsilon^2_{1,t-1}$	$+0.0241\, \varepsilon^2_{2,t-1}$	$+0.0372\, \varepsilon^2_{3,t-1}$	$-0.0193\, \varepsilon_{1,t-1}\varepsilon_{2,t-1}$	$-0.0239\, \varepsilon_{1,t-1}\varepsilon_{3,t-1}$	$+0.0600\, \varepsilon_{2,t-1}\varepsilon_{3,t-1}$	
0.0096	0.0325	0.0089	0.0274	0.0301	0.0410	
(0.3992)	(0.7428)	(4.1691)	(-0.7033)	(−0.7948)	(1.4625)	

Our findings indicate that CO_2 return volatility (conditional variance) is directly affected by its own volatility, the Brent and the natural gas returns volatility. This means that higher levels of those volatilities in the past are associated with higher conditional volatility of CO_2 returns in the current period. Additionally, the coefficients of the covariance are all also statistically significant. This means that the CO_2 volatility is not only directly affected by the volatility in the other two markets but also indirectly through the covariance. Thus we find significant direct and indirect volatility transmissions from the oil and natural gas markets to the CO_2 market at the 5% level of significance. Our results also indicate that the CO_2 volatility is affected by shocks originated in the carbon market and in the oil market but not by those originated in the natural gas market. The natural gas market shocks do not have a direct nor an indirect impact on carbon volatility (note the insignificant estimated coefficient on $\varepsilon^2_{3,t-1}$, $\varepsilon_{1,t-1}\varepsilon_{3,t-1}$ and $\varepsilon_{2,t-1}\varepsilon_{3,t-1}$ in the CO_2 conditional variance equation in Table II).

The behaviour of Brent return volatility is similar to the carbon volatility in what concerns the past volatility impacts on the present volatility. That is, Brent volatility is affected by Brent, CO_2, and natural gas past volatility both directly and indirectly through the three covariances. However, Brent volatility is not affected by any of the different shocks considered. That is, by shocks originating in the carbon, Brent or natural gas markets.

Finally, the natural gas return current volatility behaviour differs substantially from that of the CO_2 and Brent. In this case, the only statistically significant coefficients, at the 5% significance level, are those of the Brent past volatility and the shocks originating in the natural gas market. Thus, we may say that natural gas volatility is directly affected by past volatility in the oil market and its own past shocks. Note that the results of our study concerning the interaction between the oil and natural gas markets are coherent with the results obtained by Ewing et al. (2002).

5. Conclusion

This paper has investigated the transmission of volatility among the CO_2 (Phase II), oil and natural gas prices, using daily returns data with a sample period from April 2005 to December 2008.

In general, we find evidence of bidirectional volatility transmission between the CO_2 and oil markets. The natural gas market has an effect on the volatility of the other two markets but it is much less affected by them. During the sample period analysed it is a much more isolated market. As also noted by Ewing et al. (2002), current oil volatility depends on past volatility and not on specific events or economic news. In contrast, natural gas return volatility responds more to unanticipated events originated in its own market, such as supply interruptions or changes in reserves and stocks. As suggested by Soderholm (2000), we could state that gas markets are essentially “regional”, whereas the CO_2 and oil markets are more “global” in nature.

Thus, these findings might suggest that there is an opportunity for investors to diversify their risk by investing in the natural gas market. Changes in volatility in the CO_2 and oil markets will be highly correlated, whereas volatility in the natural gas market is much more independent from the others. The implication of our research for investors is that the strategy of diversifying across different commodities or energy markets may be adequate in terms of reducing portfolio risk. Specifically, for those practitioners whose current global strategy assumes that some energy markets (natural gas) remain significantly segmented, this paper provides evidence supporting their claim.

There are several possible explanations for the differences found concerning the market reactions. On the one hand, the significant volatility transmission between the oil and natural gas markets could come from the notion that these markets exhibit some degree of substitutability. On the other hand, we find significant volatility spillovers from energy markets to carbon markets because volatility is related to the rate of information flow and the CO_2 market is dependent on energy markets (CO_2 emission allowances exhibit some degree of complementarity with energy markets).

As we mentioned before, the findings of this study might be of practical importance to financial market participants for optimal portfolio allocation, asset (options) valuation, diversification, and risk management. Investors holding assets and derivatives in the CO_2, oil or natural gas markets should monitor what is happening in the other markets.

Finally, these results indicate that the conclusions for the Phase I of the EU ETS concerning the determinants of EUA prices obtained by Mansanet-Bataller et al. (2007) and Alberola et al. (2008) would probably held in Phase II. That is, oil and natural gas markets will continue to influence CO_2 prices due to volatility transmission from the formers to the later.

References

Alberola, E., Chevallier, J. and Chèze, B., "Price drivers and structural breaks in European carbon prices 2005-2007", *Energy Policy*, vol. 38, no. 2, pp. 787-797, 2008.

Alberola, E. and Chevallier, J., "European carbon prices and banking restrictions: evidence from Phase I (2005-2007), *The Energy Journal*, forthcoming.

Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003. "Establishing a Scheme for Greenhouse Gas Emission Allowance Trading within the Community and Amending Council Directive 96/61/EC". Official Journal of the European Union L275/32. 25th October 2003.

Ellerman, A.D. and Buchner, B.K., "The European Union Emissions Trading Scheme: origins, allocation and early results", *Review of Environmental Economics and Policy*, vol. 1, no.1, pp. 66-87, 2007.

Estrada, J. and Fugleberg, O., "Price elasticities of natural gas demand in France and West Germany", *Energy Journal*, vol. 10, pp. 77–90, 1989.

Ewing, B.T. Malik, F. and Ozfidan, O., "Volatility transmission in the oil and natural gas markets", *Energy Economics*, vol. 24, pp. 525–538, 2002.

Mansanet-Bataller, M., Pardo, A. and Valor, E., "CO_2 prices, energy and weather, *The Energy Journal*, vol. 28, pp. 73-92, 2007.

Mansanet-Bataller, M. and Pardo, A., "What you should know about carbon markets", *Energies*, vol. 1, pp. 120-153, 2008.

Serletis, A. and Herbert, J., "The message in North American energy prices", *Energy Economics*, vol. 21, pp. 471–483, 1999.

Soderholm, P., "Fuel flexibility in the West European power sector", *Resources Policy*, vol. 26, pp. 157–170, 2000.

Stern, N., "The Economics of Climate Change", Cabinet Office-HM Treasury, Cambridge, 2006.

Uhrig-Homburg, M. and Wagner, M., "Futures price dynamics of CO_2 emission certificates – an empirical analysis", unpublished, University of Karlsruhe, 2007.