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European Carbon Markets and the Global Financial Crisis

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Abstract

This paper considers investment characteristics of the European Union Emissions Trading Scheme (EU ETS) during the Global Financial Crisis (GFC). We show that European emissions trading markets demonstrate substantial price volatility, risk-adjusted return under-performance and positive correlations with other markets during the peak of the crisis. The poor investment performance of carbon assets during this period suggests that investors may need to avoid buy-and-hold strategies, reduce their portfolio weightings and consider other alternative investments until there is an improvement in economic conditions and, importantly, greater certainty with global climate change policy.

Key words: carbon markets; investment; price return performance, global financial crisis

Track: F&A 20. Financial Markets

1. Introduction

The introduction of carbon or “emissions” trading markets has been driven primarily by environmental concerns about climate change. From an economic perspective, the logic is straightforward. Emissions are limited by permits, which can be traded, and hence a price for a set amount of emissions is determined by market forces. It is argued that this price mechanism ultimately leads to a shift in production from high to low emissions-producing industries and therefore a better environment.

Emissions markets also potentially offer new investment opportunities. In addition to trading in emissions for scheme compliance purposes (for example, buying/selling permits to cover emissions greater/less than those allocated), risk management, arbitrage and speculation represent other reasons for trading. Hence, emissions markets not only represent an opportunity to reduce pollution globally but also offer exciting growth prospects for a range of investors and investment purposes.

Past investment market research suggests that in periods of high volatility, new and emerging markets demonstrate diverse performance and so provide much needed diversification benefits to investors (Barry et al. 1998; Harvey 1993; Roll 1988). However, there is also evidence to suggest that these benefits vary over time and, in particular, are reduced during economic downturns (Conover et al. 2002), precisely when investors are seeking to minimise their exposure to downside risk. During financial crises, contagion and increasing interdependence among markets is evident (Patel and Sarkar 1998; Cheung et al. 2010), decreasing, at least in the short-term, diversification benefits.

In this paper, we explore whether this phenomenon also applies to the new emissions markets. Specifically, we focus on the European Union Emissions Trading Scheme (EU ETS), the world’s first (and largest) mandatory multi-country, multi-sector cap-and-trade emissions trading scheme. The size, scope, organisation and history of the EU ETS enhance its significance in terms of examining carbon market investment characteristics. Although the EU ETS has only been operating for a relatively short period, having commenced operation in 2005, this operating period includes a crisis episode, the global financial crisis (GFC).

The GFC, the largest since the Great Depression, began in the world’s major economy with the U.S. subprime mortgage crisis in 2008. This sparked a credit crunch that spilled over into many other economies and markets, especially those more financially integrated and liberalised (Claessens et al. 2010; Cheung et al. 2010). Asset prices fell, intense liquidity problems arose, risk premiums increased and consumer spending decreased. Economies began to contract, sparking a new round of dramatic selling and price falls across global financial markets, particularly in countries with high international trade and debt exposures. We examine investment characteristics of the EU ETS during this period of crisis and into the beginning of recovery.

This paper is structured as follows. We first provide a background on the EU ETS and studies examining this market. This is followed by a description of the data used in this study. The paper then outlines the performance of the EU ETS and key international equity markets during a period covering the peak of the GFC and beginning of recovery, followed by a consideration of price activity. We then examine and discuss correlations between EU ETS and key equity markets. The final section provides conclusions.

2. EU ETS

The EU ETS commenced operation on 1 January 2005. By 2008, transactions totalled almost US$92 billion, representing 73% of the total value of carbon markets worldwide, and

secondary markets had become increasingly functional, liquid and transparent (World Bank, 2009). The EU ETS is a mandatory “cap-and-trade” carbon trading scheme. Under such schemes, the regulator sets a maximum quantity of emissions that may be discharged over some fixed time period, divides that quantity into allowances (called European Union Allowances or “EUAs” in the case of the EU ETS), and auctions or otherwise freely allocates them to emitters (“the cap”). Over the commitment period, participants who cannot keep their emissions under the cap can fulfil their scheme obligations by purchasing allowances from those that have invested in efficient technologies or used less carbon-intensive energy sources to reduce their emissions or both (“the trade”) (Pearce 2005). The net effect of these transactions is that scheme participants are able to reduce their emissions at the lowest possible cost. Moreover, carbon trading allows emitters who can cut their emissions cheaply to sell reductions to those who find it more expensive to take action (Tyrell 2006).

The EU ETS is designed to operate in three Phases to enable learning and refinement of the scheme to occur. During Phase I (2005-07) the EU ETS covered over 12,000 emitters covering energy activities, mineral oil refineries, coke ovens and companies carrying out activities in ferrous metals, cement, glass, brick making, and pulp and paper industries. Around 40% of EU carbon dioxide emissions were covered by these emitters (Milunovich et al. 2007).

Phase I, however, was fraught with controversial events and issues. Over-allocation of allowances relative to actual emission levels led to a price collapse from a high of almost €30/tonne in April 2006 to under €1/tonne in December 2007 (Barclays Capital 2008). The release of the first verified emissions data indicated that permits had been over-allocated by around ninety-five megatonnes (Mt) (2,101.3Mt allocation versus emissions of 2,006Mt) (Burke 2006). It became apparent that the market was not as short as expected, particularly with regard to power producers needing fewer EUAs (Alberola 2006). Notably, it took over a year for the surplus EUAs in the market to push the EUA price towards the theoretical zero value. Inexperienced carbon market participants and utility companies holding onto their permits (anticipating higher emissions at the end of the year) contributed to this phenomenon (Barclays Capital 2008).

In Phase II (2008-2012), regulators refined the scheme dynamics based on lessons learnt from Phase I in an attempt to provide a more robust and efficient market operation. Some of the steps taken in implementing Phase II included:

- improved handling of price sensitive information;
- allowances reissued at the beginning of Phase II at approximately €20;
- lower allocations under National Allocation Plans to increase liquidity;
- broader coverage of industries (for example, chemical, aluminium and aviation/transport) and gases (Milunovich et al. 2007);
- governments can auction EUAs to a maximum of 10% of the allocation; and
- EUAs in Phase II will be bankable into Phase III (2013-16), providing price support and preventing a Phase I style price collapse caused by an inability to carry over unused Phase I EUAs into subsequent periods (World Bank 2008).

From a financial market perspective, research to date examining the EU ETS has focused on its efficiency and dynamic linkages (see, for example, Boutaba 2009; Charles et al. 2011; Chevallier 2010; Daskalakis and Markellos 2008; Lu and Wang 2010; Montagnoli and de Vries 2010; Uhrig-Homburg and Wagner 2009). The evidence suggests joint price discovery in spot and forward carbon markets and therefore a reasonable degree of informational efficiency. With the exception of Daskalakis and Markellos (2008) who suggest that the EU ETS markets may have been weak-form inefficient in Phase I.

The impact of the GFC on the EU ETS has been examined from other perspectives and has led to some criticism of the scheme and its ability to fulfil its environmental aims. Arguably, low carbon prices and high volatility limit the effectiveness of long-term planning for sustainable innovations (Knoll and Engels 2010). Furthermore, while the GFC has caused a reduction in emissions as production output has decreased, it has been argued that the case for emissions trading schemes has been undermined as a result (Butcher and Stilwell 2009). Emissions from reporting EU ETS installations fell 11% in 2009 mainly as a result of the GFC and total emissions were lower than the total allocation of allowances (World Bank 2010). This reduced demand for EUAs (Skjærseth 2010) and has resulted in surplus allowances that are now bankable. Hence as recovery occurs, these surplus allowances can be used to fulfil emitter obligations, reducing the costs of increasing production and emissions, and slowing the price mechanism's ability to achieve the aims of the EU ETS. Although the World Bank (2009) argues that many of the surplus allowances were sold during the peak of the financial crisis in order to raise cash, it could be argued that this is just a timing issue in profit taking and that the scheme's ability to deal with economic cycles needs to be carefully considered.

While the ultimate success of the EU ETS must be measured against its ability to achieve the main aim of reducing global carbon emissions, a well-functioning emissions market in a financial sense is a necessary condition. Liquidity in the market will be improved by investor trading in addition to compliance trading. Therefore, in the remainder of this paper we focus on exploring the EU ETS from an investor perspective during a period of financial crisis.

3. Data

The time period of interest in this paper coincides with the GFC. This began with increased uncertainty surrounding credit markets in May/June 2008, followed by initial falls in many stock markets around the world during August/September 2008, a long period of tumbling prices in late 2008, and slow recovery from early 2009. The crisis period also coincides with the early stages of Phase II of the EU ETS. Therefore, we begin our analysis at the start of Phase II on 25 February 2008 and use daily closing EU ETS Allowance price observations through until 5 March 2010. Observations are categorised as either spot (*EUAS*) or forward (*EUAF-2010, EUAF-2011,* and *EUAF-2012*) price series.

We compare carbon market investment and performance to the following international equity price indices: the Dow Jones EURO STOXX total market index (*DJES*), Standard and Poors (S&P) 500 index (*SP500*), S&P All Ordinaries index (*SPAO*), and Shanghai Stock Exchange Composite index (*SSECI*). All of the equity indices are ranked by weighted market capitalisation.

In the absence of a comprehensive benchmark that incorporates carbon and all other risky assets, *DJES* is selected as a relevant market proxy for carbon assets and the European economy combined. The EU 10-year government bond yield is employed to provide a risk-free rate (*RFR*) against which asset performance can be benchmarked.

Data are collected from various exchanges and historical price databases. *EUAS* data utilised in this study are obtained from BlueNext and *EUAF* data from the European Climate Exchange. *DJES* index data are compiled from the Dow Jones EURO STOXX, and the *SP500*, *SPAO*, and *SSECI* index data sourced from Yahoo Finance. *RFR* data are collected from the European Central Bank.

The daily log returns of the price series are calculated using the continuously compounded formula:

$$R_t = \ln\left(\frac{P_t}{P_{t-1}}\right), \qquad (1)$$

where *Pt* is the price series at time *t*, *ln* is the natural logarithm, and *Rt* represents the log return series.

4. EU ETS Market Performance

The summary statistics provided in Table 1 indicate that the nominal return performance of carbon markets compared to international equity markets is poor. Underperformance is highlighted by the annualised log returns of both spot and forward price series. *EUAS* and *EUAF-10-11-12* delivered annualised returns of -19.85%, -25.03%, -24.73%, and -24.40% in Phase II respectively. Returns were below the European equity market benchmark return (-10.22%). Negative returns across all price series reflect the dampening effect of the GFC and ensuing global recession on carbon and international equity market investment.

Table 1: Summary Statistics

Series	Min. return (%)	Max. return (%)	Mean return (%)	Return p.a. (%)	Std Dev. (%)	Beta	Sharpe ratio	Jarque-Bera
EUAS	-10.29	10.55	-0.08	-19.85	2.66	1.25	-8.93	61*
EUAF-10	-9.30	11.35	-0.10	-25.03	2.64	1.25	-10.95	80*
EUAF-11	-9.06	11.53	-0.01	-24.73	2.63	1.22	-10.89	84*
EUAF-12	-9.33	11.75	-0.01	-24.40	2.54	1.17	-11.13	103*
DJES	-7.87	9.30	-0.04	-10.22	1.85	1	-7.63	386*
SP500	-9.47	10.96	-0.03	-8.14	2.12	N/A	-5.69	542*
SPAO	-8.55	5.36	-0.03	-7.91	1.60	N/A	-7.38	177*
SSECI	-6.98	9.03	-0.07	-17.26	2.23	N/A	-9.51	52*

Notes: This table reports summary statistics for EU ETS and equity markets 25 February 2008 to 5 March 2010 which represents 530 observations for each price series. *EUAS* is the spot EU ETS market price series. *EUAF-10, EUAF-11 and EUAF-12* are the forward EU ETS market price series for 2010, 2011 and 2012 respectively. *DJES* is the Dow Jones EURO STOXX total market index. *SP500* is the Standard and Poors (S&P) 500 index. *SPAO* is the S&P All Ordinaries index. *SSECI* is the Shanghai Stock Exchange Composite index. The summary statistics are minimum daily return, maximum daily return, mean daily return, annualised return, standard deviation, beta, Sharpe ratio and the Jarque-Bera test of normality. * denotes statistical significance at 5% level and hence rejection of the null hypothesis of a normal distribution in the price series.

Price volatility is clearly reflected in carbon markets across the period by the large spread between minimum and maximum returns, high standard deviations and betas. Beta is calculated using *DJES* as the reference market. *EUAS* and *EUAF-10-11-12* had standard deviations/betas of 2.66%/1.25, 2.64%/1.25, 2.63%/1.22, and 2.54%/1.17 respectively. Standard deviations were higher than the European equity market benchmark standard deviation (1.85%) and beta (1.00), indicating that carbon was riskier than the broader market during the GFC. Also, as spot and forward carbon betas are positive and greater than one, this suggests that carbon markets, on average, exhibit more systematic risk than the broader European equity market. The volatility in carbon markets displayed during the period is in line with expectations given that emerging markets tend to display such price characteristics during the early stages of market growth.

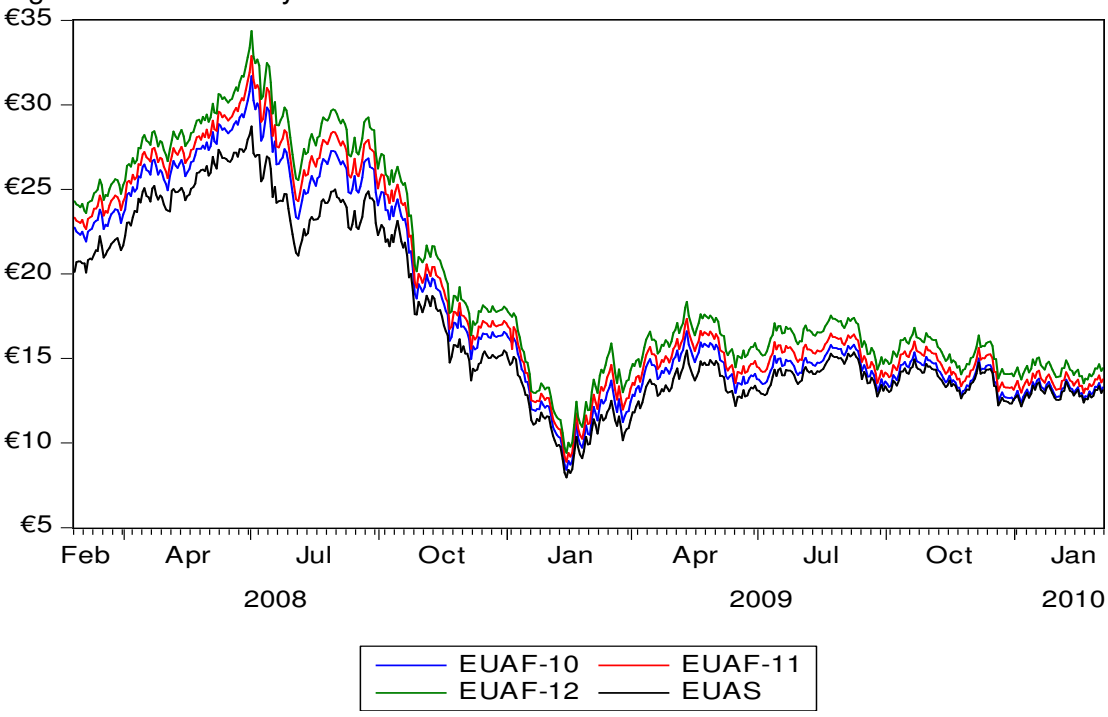
Table 1 also shows the Sharpe (1966) ratio for each price series, calculated as the ratio of the average annualised return less the risk free rate to the standard deviation. The ratio therefore indicates the excess return earned per unit of total risk and so higher ratios denote better risk-adjusted performance. Comparison of the Sharpe ratios shows that *EUAS* (-8.93) and *EUAF-10-11-12* (-10.95, -10.89, and -11.13 respectively) underperformed *DJES* (-7.63) and the other international equity price series (except *EUAS* versus *SSECI*) on a risk-adjusted basis.

The last column of Table 1 shows statistics relating to the shape of the return distributions. The Jarque-Bera (1980) test statistics indicate that the log return series of all carbon and international equity markets do not follow a normal distribution. However, non-normality of returns is not an unusual phenomenon in financial time-series (Ma 2004).

5. Price Activity

In this section, we examine price activity in the carbon markets during our study period. In an efficient market, futures prices should move conjointly with spot prices (Fama 1991). This is portrayed in Figure 1. During the period spot and futures prices moved closely in line with each other, suggesting an efficient flow of information between these markets and conditions conducive to effective risk management.

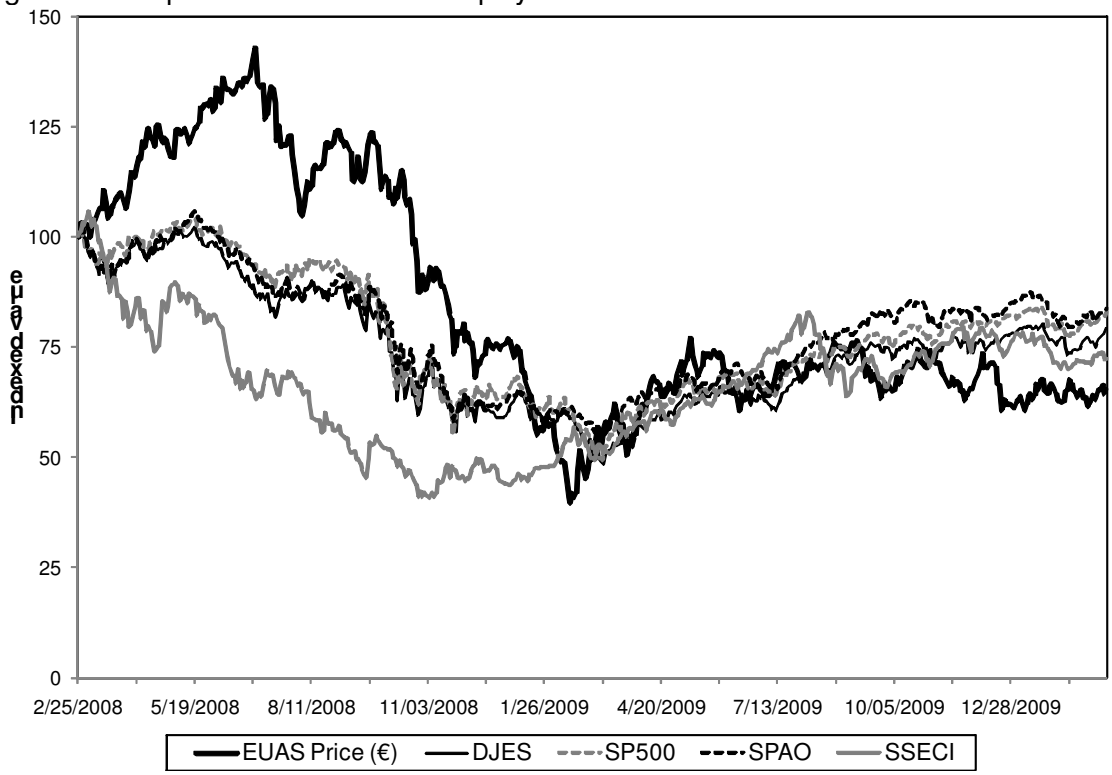
Figure 1: Price Activity in the Carbon Markets



Further consideration of Figure 1 shows the commencement of a downward trend in carbon prices in late May 2008. This coincides with increased uncertainty over the future of U.S. financial institutions such as America International Group (AIG), Bear Stearns, Freddie Mac, Fannie Mae and Lehman Brothers. Worldwide, asset prices were falling and carbon contracts became no exception. By January 2009 international financial markets had bottomed and carbon markets rallied. However, the recovery was short-lived for carbon markets, reaching their post-crisis peak in April 2009. Carbon markets maintained prices around this peak until the end of the period covered by our data set.

Carbon price activity can also be compared to international equity markets, as shown in Figure 2. Equity markets were already falling at the beginning of Phase II of the EU ETS and it was not until May 2008 that the carbon market followed suit. SSECI fell more sharply than other equity markets and bottomed out earlier. The developed markets in the figure (DJES, SP500 and SPAO) move closely throughout the entire period under consideration, as might be expected from these highly integrated markets. The rally in equity markets after the beginning of 2009 lasted a little longer than carbon markets, and despite a flattening out in all markets by the middle of 2009, equity markets had clearly regained more ground.

Figure 2: Comparison of EUAS and Equity Market Price Series



There are two likely reasons for the lacklustre recovery of carbon prices. First, it became clear that a global economic recovery was not going to happen quickly. Consequently, demand for carbon abatement remained soft, resulting in carbon markets trading sideways Second, there was increasing uncertainty surrounding international agreements on responses to climate change. This uncertainty peaked when negotiations broke down at the United Nations Framework Convention on Climate Change (UNFCCC) in Copenhagen in December 2009.

6. Co-movements among carbon markets and with equity markets

Having considered key performance statistics and price activity during the study period, we now examine correlations between spot and forward carbon prices, and correlations between the carbon markets and equity markets. Low correlations between asset prices are a favourable occurrence for portfolio investors, as non-systematic risk can be lowered and returns enhanced by combining such assets. Correlations between financial assets can also have implications for market efficiency theory (for instance, two asset prices that share a robust positive correlation or “co-movement” may infer return predictability in one or the other, or both) (Harvey 1993).

Correlations between carbon markets and equity markets are shown in Table 2. The carbon markets exhibit perfect or almost perfect positive correlations, reflecting our earlier comments about efficient price formation between spot and forward carbon prices during the study period. Relationships between carbon markets and equity markets are not as high but also demonstrate positive correlations. Carbon markets are most correlated with DJES, SP500 and SPAO, with strong positive correlations ranging between 0.66 and 0.77. Correlations with the Chinese stock market (SSECI) were also positive but much lower than other equity markets, ranging from 0.19 with the spot market and 0.13 with the 2012 forward market. It is also worth noting that as depicted in Figure 2, the correlations between the DJES, SP500 and SPAO developed equity markets are close to 1.

Table 2: Correlations of carbon and international equity markets

	EUAS	***EUAF-10***	***EUAF-11***	***EUAF-12***	***DJES***	***SP500***	***SPAO***	***SSECI***
EUAS	1.00							
EUAF-10	1.00	1.00						
EUAF-11	1.00	1.00	1.00					
EUAF-12	0.99	1.00	1.00	1.00				
DJES	0.77	0.74	0.73	0.72	1.00			
SP500	0.76	0.74	0.73	0.73	0.99	1.00		
SPAO	0.72	0.68	0.70	0.66	0.98	0.98	1.00	
SSECI	0.19	0.14	0.14	0.13	0.64	0.63	0.69	1.00

This table reports correlations among the log prices of EU ETS markets and with log indices for international equity markets during pre- and post-Lehman Brothers collapse periods. *EUAS* is the spot EU ETS market price series. *EUAF-10*, *EUAF-11* and *EUAF-12* are the forward EU ETS market price series for 2010, 2011 and 2012 respectively. *DJES* is the Dow Jones EURO STOXX total market index. *SP500* is the Standard and Poors (S&P) 500 index. *SPAO* is the S&P All Ordinaries index. *SSECI* is the Shanghai Stock Exchange Composite index.

These high correlations may reflect the general tendency for diversification benefits to fall during crisis events. Certainly, carbon markets and international equity markets are not perfectly positively correlated, which indicates some diversification opportunities are available. However, the greatest diversification benefits would appear to be gained by combining investments in the emerging carbon market with those in the segmented and geo-politically insulated Chinese stock market. A combination of carbon and more established markets would seem to provide less benefit.

The correlations, however, are for the entire period under study. Consideration of these correlations in combination with Figure 2 makes it reasonable to suggest that the low positive correlations between carbon markets and the Chinese stock market may simply be a reflection of the divergence of these two series at the beginning of the period. While the carbon market was still rising in the early part of the period before ongoing impacts on real economy and emissions were fully understood, the Chinese stock market was falling on the back of overstated values and speculation over its ability to maintain growth as contagion spread. By the time of recovery, however, it is clear that all markets considered here appear to move quite closely.

7. Conclusions

In this paper we have examined the investment characteristics of the EU ETS from the beginning of Phase II through the period of tumbling prices in financial markets due to the onset of the GFC and into the beginning of price recovery. While previous studies of this market have considered its efficiency and dynamic linkages, return and risk characteristics from an investment perspective have been overlooked. Our study fills this gap by providing a

presentation of a range of carbon market investment characteristics and by considering these characteristics within the wider context of the GFC.

Our results show that European carbon markets demonstrate investment characteristics such as high volatility, risk-adjusted return under-performance and positive correlations with four key international equity markets. It appears that global climate change policy uncertainty and the ongoing GFC have promoted a highly speculative and risky trading environment for carbon assets and reduced their desirability as a viable investment vehicle. If these trends continue, the investment potential of carbon markets is doubtful.

Our carbon market findings are consistent with Errunza (1997) and Blavy (2002) in that while large price swings are not unique to emerging markets these new markets exhibit a higher degree of volatility in comparison to developed markets. However, they are inconsistent with Harvey (1993) and Roll (1988) who argue that during periods of general high volatility (as in the case of GFC) emerging markets should demonstrate diverse performance and provide much needed diversification benefits. In contrast, we found that during the GFC period correlations between carbon markets and developed equity markets were strongly positively correlated. Instead, it would seem that emerging market participants like those in China may receive the greatest diversification benefits from investing in the EU ETS.

Upon consideration of the investment characteristics highlighted in this paper, undermining factors, such as market fragmentation/segmentation, scarcity of information and education and a low degree of competition, may have constrained the flow of financial information, restricted market growth, and led to the emergence of inefficiencies and predictable price behaviour in European carbon markets. Overall, the poor investment characteristics associated with carbon assets to date suggests that investors may need to avoid buy-and-hold strategies, reduce their portfolio weightings and consider other alternative investments until there is an improvement in economic conditions and, importantly, greater certainty with global climate change policy. If non-compliance investment trading is avoided, however, liquidity in the carbon markets will be reduced and the ultimate aims of such schemes may be more difficult to achieve.

8. References

Alberola, E. (2006), The informational efficiency of the EU ETS: An empirical evaluation on the spot and futures prices, Working Paper, University of Paris, France.

Barclays Capital (2008), *Introduction to the Emissions Market*, Barclays, London, U.K.

Barry, C.B., Peavy, J.W. III and Rodriguez. M. (1998), Performance characteristics of emerging capital markets, *Financial Analysts Journal*, 54 (1), pp. 72-80.

Blavy, R. (2002), Changing volatility in emerging markets: A case study of two Middle Eastern stock exchanges, *Revue Entente Cordiale*, Autumn-Winter, pp. 1-35.

Boutaba, M.A. (2009), Dynamic linkages among European carbon markets, *Economics Bulletin*, 29 (2), pp. 499-511.

Burke, M. (2006), Drop in EU carbon prices baffles analysts, *Environmental Science and Technolog*, 40 (15), pp. 4534-4535.

Butcher, B.S. and Stilwell, F. (2009), Climate change policy and economic recession, *Journal of Australian Political Economy*, 63 (June), pp. 108-125.

Charles, A., Darné, O. and Fouilloux, J. (2011), Testing the martingale difference hypothesis in CO_2 emission allowances, *Economic Modelling*, 28 (1-2), pp. 27-35.

Cheung, W., Fung, S. and Tsai, S-C. (2010), Global capital market interdependence and spillover effect of credit risk: evidence from the 2007-2009 global financial crisis, *Applied Financial Economics*, 20 (1-2), pp. 85-103.

Chevallier, J. (2010), A note on cointegrating and vector autoregressive relationships between CO_2 allowances spot and futures prices, *Economics Bulletin*, 30 (2), pp. 1564-1584.

Claessens, S., Dell'Ariccia, G., Igan, D. and Laeven, L. (2010), Cross-country experiences and policy implications from the global financial crisis, *Economic Policy*, 25 (62), pp. 267-293.

Conover, C.M., Jensen, G.R. and Johnson, R.R. 2002, Emerging Markets: When are they worth it? *Financial Analysts Journal* 58(2), 86-95.

Daskalakis, G. and Markellos, R. (2008), Are the European carbon markets efficient? *Review of Futures Market*, 17 (2), pp. 103-128.

Errunza, V.R. (1997), Research on emerging markets: past, present, and future, *Emerging Markets Quarterly*, 1 (3), pp. 5-18.

Fama, E. F. (1991), Efficient capital markets: II, *Journal of Finance*, 46 (5), pp. 1575-1617.

Harvey, C. (1993), Portfolio investment using emerging markets and conditioning information, Working Paper, World Bank, Washington DC.

Jarque, C.M. and Bera, A.K. (1980), Efficient tests for normality, homoskedasticity and serial independence of regression residuals, *Economics Letters*, 6 (3), pp. 255-259.

Knoll, L. and Engles, A. (2010), Exploring the linkages between carbon markets and sustainable innovations in the energy sector: lessons from the EU Emissions Trading Scheme, in Engles, A. (ed.) *Global Transformations towards a Low Carbon Society Working Paper Series*, 2, University of Hamburg, Klima Campus, Hamburg.

Lu, W. and Wang, W. (2010), Weak-form efficiency of European Union emission trading scheme: evidence from variance ratio tests, *International Journal of Green Economics*, 4 (2), pp. 183-196.

Ma, S. (2004), *The Efficiency of China's Stock Market*, Ashgate Publishing, Aldershot, U.K.

Milunovich, G., Stegman, A. and Cotton, D. (2007), Carbon trading: theory and practice, *JASSA*: *The FINSIA Journal of Applied Finance*, 3, pp. 3-9.

Montagnoli, A. and deVries, F.P. (2010), Carbon trading thickness and market efficiency, *Energy Economics*, 32 (6), pp. 1331-1336.

Patel, S.A. and Sarkar, A. (1998), Crises in developed and emerging stock markets, *Financial Analysts Journal*, 54 (6), pp. 50-59.

Pearce, F. (2005), A most precious commodity, *New Scientist*, 185 (2481), pp. 6-7.

Roll, R. (1988), The international crash of October 1987, *Financial Analyst Journal*, 44 (5), pp. 19-35.

Sharpe, W.F. (1966), Mutual fund performance, *The Journal of Business*, 39 (1), pp. 119-138.

Skjærseth, J.B. (2010), EU emissions trading: legitimacy and stringency, *Environmental Policy and Governance*, 20, pp. 295-308.

Tyrell, K. (2006), Linking the world with emissions trading, *ENDS Report*, 380, pp. 34-37.

Uhrig-Homburg, M. and Wagner, M.W. (2009), Futures price dynamics of CO_2 emission certificates - an empirical analysis, *Journal of Derivatives*, 17 (2), pp. 73-88.

World Bank (2008), *State and Trends of the Carbon Market*, World Bank Institute, Washington DC.

World Bank (2009), *State and Trends of the Carbon Market*, World Bank Institute, Washington DC.

World Bank (2010), *State and Trends of the Carbon Market*, World Bank Institute, Washington DC.