CEVI
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Energy and Value Letter

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- Editor-in-chief John Simpson shows his appetite for linking energy economics and finance.
- CEVI president André Dorsman takes a detour on several activities of a small but very alive association
- Steven von Eije, Henk von Eije and Wim Westerman discuss characteristics of energy carriers and renewable energy production
- Alexander Afonin, Don Bredin and Cal Muckley demonstrate the benefits of carbon credit futures for diversification purposes in portfolio management

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Energy and Value Letter

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Editorial Policy

The Energy and Value Letter brings together academics and practitioners worldwide to discuss timely valuation issues in the energy sector. It publishes news from the Centre for Energy and Value Issues (CEVI), its linked organizations and others (including calls for papers), practitioners' papers: short articles from institutions, firms, consultants, etcetera, as well as peer-reviewed academic papers: short articles on theoretical, qualitative or modeling issues, empirical results and the like. Specific topics will refer to energy finance in a broad sense. All of the papers are peer reviewed. The journal welcomes unsolicited contributions. Please e-mail to **energyandvalue@gmail.com**, c/o Özgür Arslan, a copy of a news item or a completed paper. Include the affiliation, address, phone, and e-mail of each author together with appropriate JEL classifications with your contribution. A news item should not have more than 400 words and a paper should not exceed 3.000 words.

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Energy and Value Letter

ON ENERGY ECONOMICS AND FINANCE

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I am happy with this issue of the Energy and Value Letter in that it shows the wealth of energy and value issues in just two academically and practically relevant papers. Steven von Eije, Henk von Eije and Wim Westerman relate the characteristics of energy carriers to the sources of renewable energy production. In doing so, they link energy economics with corporate finance. In this issue we also give ample the floor to Alexander Afonin, Don Bredin and Cal Muckley, who investigate emission allowances as a stand-alone investment asset class, as well as its portfolio diversification implications. In doing so, the authors exemplify how to link energy economics with financial markets.

This brings me to the central theme of the CEVI books, which CEVI publishes with Springer Verlag. The first book edited by CEVI, “Financial Aspects of Energy” has been well received and the association seeks to continue its work in publishing worthwhile research on the energy issues particularly from the perspectives of macro and micro economics and financial economics. The first chapter of the new book, which should be published later this year, discusses many of the points raised below.

There are of course many critical areas of interest in areas that relate either generally or specifically to fossil fuels and alternatives, energy efficiency, the impact of energy on political economics, safety issues, climate change, sustainability and renewables, energy independence and security, the transportation of energy resources, electricity generation and so on. The second book, edited by John Simpson, André Dorsman and Wim Westerman, in some way touches all of those broad issues either explicitly or by implication. The book cannot hope to deal with all of the current global energy issues in detail, but it still represents a genuine effort to draw the attention of those interested in applied research in several important areas of energy economics.

But for now, let us first enjoy this seventh issue of the Energy and Value Letter!

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A SHORT NOTE FROM THE CEVI BOARD

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In October 2011, Springer published the first CEVI book, Financial Aspects in Energy and we hope to publish the second book, Energy Economics and Financial Markets, in October this year. John Simpson is taking the lead with this text that bridges economic and financial topics with global energy issues. The book exists of four parts, part 1: Supply and Demand, part 2: Environmental issues and Renewables, part 3: The Dynamics of Energy Derivatives Trading, and part 4: Finance and Energy. Contributors from several countries author the chapters.

Mehmet Karan organized the fourth CEVI Energy School in Turkey in October 2011. Due to the fact that the Turkish president Gül will visit The Netherlands in April 2012, we decided to postpone the fifth Energy School to September, 24-29. CEVI wants to narrow the gap between scientists and practitioners in the energy area. CEVI is therefore grateful that several organisations are willing to participate in this meeting by means of lectures, business visits etc. Amongst others, in that week we will visit the APX-Endex exchange and also a windpark.

The fourth CEVI conference will be held in Chicago, May 2013. The organisation of that conference is in the hands of Paul Prahbaker. Paul is associate dean of the NIU (Northern Illinois University) College of Business. To prepare this conference, Paul will visit Mehmet Baha Karan in Ankara in April 2012 and a month later he will go to Chicago. To stimulate academics and others to present their best research during the CEVI conferences, we will select the papers to be presented in a welcoming but strict way. We aim to publish the most fitting papers in the Springer Energy books series.

Due to priorities that she had to set, Jennifer Westaway from Curtin University, Western Australia, left the CEVI board. We are grateful to her for her support over the years. With her law background, she had a special and highly valued input in our organization’s activities.

Although our organization is small, we are alive and kicking. We engage in the editing of books, maintain an Energy School, organise conferences and publish the Energy and Value Letter. As president of CEVI, I welcome your participation in the establishment of CEVI as a linking pin between academics and practitioners who engage in value-related issues on energy.

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Energy and Value Letter

Characteristics of Energy Carriers and Renewable Energy Production

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Abstract

In this paper we relate the characteristics of energy carriers to the sources of renewable energy production. Renewable energy often has a higher intermittency rate than fossil energy production, but with more possibilities for decentralization and less location limitations. Yet, much arable land may be needed. Whilst renewable energy production is still more expensive than its fossil counterpart, this is changing.

1. Introduction

What we now call alternative energy, has not been considered so previously. Historically mainly the use of wood and other plant products (biomass) was the major source of energy, and it is still an important source of energy in many developing countries. Later, wind energy and water power became important. Only now, after the industrial revolution where the massive use of coal, gas and oil became the major sources of worldwide energy production, we call these “alternative”, because they do not use fossil fuels. Nowadays, nuclear and geothermal energy, tide and wave based electricity and waste-based sources of energy production are included amongst these alternative sources. While these types of energy do not use fossil fuels, we exclude them in this paper, as we primarily focus on renewable energy sources (which excludes nuclear energy) and the relatively larger sources of renewable energy originating from the use of plants, wind, sun, and water._Nowadays, all renewable energy sources are about 7.8% of the total primary energy supply in the world of which hydropower is the largest with 6.5 percentage points (BP, 2011).

In section 2, the main energy carriers are characterized. Next, section 3 zooms in on the characteristics renewable energy production. Section 4 concludes.

2. Characteristics of the main energy carriers

The main energy carriers are solid fuels, liquid fuels, gaseous fuels and electricity. These carriers can be characterized by storability, end use flexibility and efficiency, transport fixed costs, transport variable costs and transmission losses.

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Storability

Solid fuels are the easiest to store, as no precautions are required to keep the solid fuels in one place. *Liquid fuels* are relatively easy to store since the only requirement is that the storage is water tight. *Gaseous fuels* can also be stored. The downside is, however, that gaseous fuels have low energy content per volume unit. To solve this issue the gaseous fuels are usually pressurized. The material that the reservoir is built from needs to be able to withstand high pressures. *Electricity* is still difficult to store. Most storage devices like batteries have a low efficiency; the higher efficiency batteries are still very expensive.

End use flexibility and efficiency

Solid fuels have the lowest end use flexibility; they can be employed as a heating source, which includes the creation of steam (for e.g. electricity generation). Solid fuels are quite inefficient when used for cooking. *Liquid fuels* are mostly used for transport purposes; this is due to the high energy density per volume unit, though they are also used for heating or electricity production. *Gaseous fuels* are mainly used for heating, but can be efficiently used for cooking or electricity production too. Gas can also be used in transport if it is compressed or liquefied to increase the energy per volume unit. *Electricity* is mostly used for electrical appliances. It is also possible to heat, cook or drive on electricity, even though this is less often done due to inherent conversion inefficiencies when fossil fuels are used for electricity production.

Transport infrastructure fixed costs

Solid fuels have low fixed transportation costs, as they can be transported by road, ship or rail, where the carriers can also be used to transport alternative goods. Dedicated investment costs are therefore low. *Liquid fuels* are often transported by pipeline; in that case the fixed costs are high since the pipelines have to be constructed. In case of transport by truck, ship or train, the fixed costs go down but the variable costs are generally higher than those of solid fuels. *Gaseous fuels* transport infrastructure costs are relatively high; the pipelines are laid under-ground and have to withstand the pressure required for transport. *Electricity* transport infrastructure is usually installed above ground. This makes the infrastructure costs of electricity relatively low, even though the material for cables is becoming increasingly expensive.

Transport variable costs

Solid fuels have a high weight-to-energy ratio, and are therefore expensive to transport. In addition they have a relatively low energy density per volume unit, which also adds to the transport costs. Since it’s usually transported by truck, ship or rail, a lot of energy is required for transportation. In case *liquid fuels* are transported by pipeline, the variable transport costs are low. Only a limited amount of pressure, and therefore energy, is required to transport liquid fuels. When they are transported by truck, ship or train, the variable costs rise. Yet these costs are lower than for solid fuels, due to high energy content per volume unit. *Gaseous fuels* are relatively cheap to transport, but large pressure required for transport in comparison to oil transport per pipeline adds to the costs. *Electricity* has the lowest variable transport costs. No additional energy is required to transport electricity.

Transmission losses

For *solid fuels*, *liquid fuels* and *gaseous fuels*, transmission losses are materially small. The transport of these energy carriers does require energy, but this has been taken into account with the variable transport costs. When transporting *electricity*, especially over longer distances, a considerable amount of transmission losses occur.

Table 1 summarises the above and scales the characteristics of the main energy carriers from 1 (lowest) to 5 (highest).

Table 1. Characteristics of the main energy carriers

	storability	end use flexibility	end use efficiency	transport fixed costs	transport variable costs	transmission losses
solid fuel	5	1	2	2	5	1
liquid fuel	4	3	1	4	2	1
gaseous fuel	3	4	3	5	3	1
electricity	1	2	5	3	1	5

3. Characteristics of fossil and renewable energy production

Fossil fuels

In order to analyse the characteristics of renewable energy, a comparison can be made with fossil fuels. Fossil fuel characteristics are quite similar. The main differences are related to the type of carrier and their total cost. The total costs are mainly a function of availability and demand. *Coal* is still very abundant and it is cheapest made available amongst the fossil fuels. *Gas* became more abundant due to the introduction of new technologies and production techniques such as liquefied natural gas (LNG) and unconventional gas. *Oil* is getting scarcer and the still rising demand is reflected in the prices. For all fossil fuels, variable production costs are low. Once a well or a mine is constructed, the variable production costs are low and have a low intermittency rate until the well or mine depletes. Location limitations are high since fossil fuels can only be extracted where the deposits are located; therefore they have a low decentralization rate. They require limited land use and all have an economy of scale effect due to the high fixed costs of the production assets.

Biomass

In global terms, biomass is the largest source of renewable energy. Biomass can be utilised as a substitute for each type of end use demand. Yet, it is mainly exploited to substitute heat demand in the form of cooking and heating houses. Else than with the other forms of renewable energy, biomass is mostly used in developing countries. Heinimö and Junginger (2009) indicate that about two thirds of the world's use of biomass is utilised there for cooking and heating. Most households in developing countries collect their wood themselves, instead of buying it in the marketplace. Therefore, investment costs are non-existent, but the collection of biomass is time intensive and it is considered to come at some variable costs. Biomass is not intermittent, since the user can choose when to use the biomass and it has a large decentralization rate, being collectable almost anywhere. The amount of land use depends on whether sources are cultivated or collected. The collection of biomass has is no economy of scale effects.

Co-firing biomass

Biomass can also be co-fired in coal fired power plants. This is a relatively cheap way of producing renewable electricity. Some adaptations are required to coal fired power plants before biomass can be used; therefore some fixed costs are involved. Biomass is usually pelletized before it is shipped to the power plant; therefore the variable production costs are considerable. As long as the biomass is available, there are no intermittency issues. Due to the nature of a coal fired power plant, the decentralization rate is low. The location limitations are small; only a steady inflow of biomass needs to be secured. Since coal fired power plants are usually located near a harbour, this is unlikely to pose a problem. Growing biomass to co-fire requires a considerable amount of land. Co-firing biomass enjoys an economy of scale effect.

Biofuels

Biofuels are still expensive; this is due to both high fixed and variable costs. The process does not have any intermittency problems and is suitable to produce at a de-central level. Biofuel refineries are ideally located near the source of biomass being used. First generation biofuels have been criticized, because the biomass employed for the production of biofuels could have served as food or feed. Second generation biofuels are made from high cellulosic items such as miscanthus and switch grass which are not suitable for consumption and therefore create less resistance. The economy of scale effect also applies to biofuels.

Biogas

Biogas installations have a high fixed cost. The variable costs are largely dependent on the biological material that the gas is produced from. If biogas is produced from manure, sewage treatment facilities or from landfills, the variable costs are low; in case of co-digestion the variable costs are considerably higher. In comparison to other forms of renewable energy, biogas has a low cost per unit of energy. Biogas is continuously produced and therefore has a very low intermittency rate. Biogas production is suitable for decentralization, even though it does enjoy economy of scale effects. Although the installations could be built anywhere, it is best to have them close to the source of biological material that the gas is produced from. The arable land use required for biogas production is largely dependent on the source of material that is used. In case energy crops are used it requires a large amount of arable land, in case of waste products, the arable land use is very low. Biogas production enjoys an economy of scale effect; this could however be offset when wet biological material is transported over long distances.

Hydroelectric power

The main source of renewable electricity is hydro (electric) power. Hydro power is mainly generated by companies that capture the energy released by falling water through a turbine which converts this into mechanical power, which drives generators to produce electricity. Hydroelectric power accounts for the largest share of (tradable) renewable energy production, 6.46% of total worldwide energy consumption is nowadays generated by hydropower installations (BP, 2011). Hydro power comes at a low total cost. There are considerable fixed costs for the production installation, but no variable costs to produce electricity (other than some maintenance). Hydro power has only a limited intermittency problem, in the absence of rain, no hydropower can be generated. The water can however be stored, allowing planned electricity production (with some limits related to the basin size). For smaller hydropower installations some decentralization is possible, but hydro power installations cannot be built everywhere. If the installation is built correctly, it does not take up a large amount of arable land; a limited economy of scale effect is possible. Hydropower could be employed as electricity storage; in case of oversupply water could be pumped into the basin, to be used at times of low supply or high demand.

Wind power

Wind production has a high cost per kWh; this is mainly due to the high fixed costs. The variable costs of wind are very low (maintenance). The fixed costs for offshore wind are considerably higher than for onshore windmills but they also have a higher utilization rate due to higher wind availability. In the absence of wind, no electricity is produced; wind power therefore has a high intermittency. Wind power has a limited decentralization rate, normally several large scale windmills are built in one location to form a windmill park. Windmills can technically be built everywhere, but the location choice is limited by i.a. the availability of wind. Windmills do not take up much arable land. Larger windmills produce at lower costs per kWh, therefore enjoying an economy of scale effect.

Photovoltaic power and concentrated solar power

Solar power can be gathered through two different technologies, concentrated solar power (CSP) and photovoltaics (PV). CSP focuses the heat of the sun by using mirrors to heat water which creates steam. With this steam, a turbine is set into motion which creates electricity. PV panels convert the energy of the sun directly. The photons in the sunlight free electrons from the atoms in the photovoltaic material so they can flow out of the cell as an electrical current. When the electrons are forced to move in one direction, they become electric current (Gore, 2009). Both technologies have a high total cost. As with wind power, this is mainly due to a high fixed cost combined with a low variable cost. Both have a high intermittency rate; although with CSP installations some heat can be stored in order to be used later. PV installations have a high decentralization rate; they can be installed at individual households. Solar PV has no economies of scale, while CSP installations enjoy large economies of scale. CSP therefore has a relatively low decentralization rate. Both PV and CSP are more effective in sunny areas, but can also produce power in the absence of the sun, and thus have only small location limitations. Neither technology requires much land.

Table 2 summarises the above and scales characteristics of sources of energy production from 1 (lowest) to 5 (highest).

Table 2. Characteristics of the main sources of energy production

	type of carrier	total cost	fixed costs (production assets)	variable production costs	intermittency	decentralisation rate	location limitations	arable land use	economy of scale effect
Oil	liquid	4	2	1	1	1	5	1	3
Coal	solid	1	1	2	1	1	5	1	3
Gas	gaseous	3	2	1	1	1	5	1	3
simple biomass	solid	1	1	2	1	5	2	3	1
cofiring biomass	electric	2	2	3	1	1	3	4	4
biofuel	liquid	4	3	3	1	4	2	5	4
biogas	gaseous	3	4	2	1	4	2	1-5	4
Hydro	electric	1	3	1	3	2	4	1	2
wind power	electric	5	4	1	5	3	3	1	5
solar pv	electric	4	4	1	4	5	2	1	1
solar csp	electric	4	5	1	3	3	2	1	4

Cost developments.

A final note on cost developments ends this section. Fossil energy generation technology is developed well and much further on the learning curve than its renewable counterpart. It is expected that the costs of renewable energy generation technology continue to fall as it progresses on the learning curve. At the same time, the costs are expected to drop as economies of scale will occur when generation capacity is expanded. On the contrary, the costs of fossil electricity generation are expected to increase due to the depletion of fossil fuels and environmental concerns (Breyer and Gerlach, 2010).

4. Conclusion

Various characteristics of energy carriers and energy sources have been identified. The specific energy carrier has a large impact on storability, end use flexibility and efficiency, transport costs and transmission losses. Currently, renewable energy production is still more expensive than its fossil counterpart. This is expected to change due to learning effects, economies of scale and rising prices for fossil fuels. Renewable energy often has a higher intermittency rate than fossil energy production. This is partly offset by the possibilities for decentralization and less location limitations. Renewable energy from biomass has less intermittency problems and can be applied de-centrally, but it requires arable land for the production of biomass.

It must be noted that there are many more determinants for the generation and use of energy, like population growth, technological development, global politics on the availability of oil, local politics on the stimulation of renewable energy sources, and the availability of capital and natural resources needed to generate capacity for renewable energy production. Of course subsidies on renewable energy and CO2 emission costs may influence the price of non-fossil fuels, while also autonomous demand changes may have their impact. Furthermore, fuel switching behaviour has been ignored.

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Energy and Value Letter

Carbon Credits and Portfolio Management

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Abstract

The European Union's Emissions Trading Scheme is the key policy instrument of the European Commission's Climate Change Program aimed at reducing greenhouse gas emissions to eight percent below 1990 levels by 2012. In addition to large CO2 emitting companies covered by the scheme, other players have entered the market with the view to use emission allowances for the diversification of their investment portfolios. The performance of this asset as a stand-alone investment, as well as its portfolio diversification implications will be investigated in this paper. The effect of adding EUA futures contracts on the mean-variance characteristics of a diversified portfolio that already contains standard asset classes is examined. Our results indicate that the market views both Phase I and Phase II EUA futures as unattractive as stand-alone investments. In a portfolio context, under no short-selling the Phase I EUA futures indicate no performance improvement. With regard to Phase II EUA futures, there are statistically significant performance improvements for the case of minimum variance portfolios only. The results demonstrate the benefits of carbon credit futures for diversification purposes in portfolio management and particularly for the case of Phase II of the European Union's Emissions Trading Scheme.

1. Introduction

The Kyoto protocol which emerged from the United Nations Framework Convention on Climate Change was adopted on the 11th of December 1997 and entered into force on the 16th of February 2005. To date 183 nations have ratified the protocol. The aim of the protocol was to stabilize the greenhouse gases emissions in order to limit global climate change. As part of the Kyoto protocol, the EU has agreed to reduce greenhouse gas (GHG) emissions by 8% (relative to 1990 levels) by 2012. In order to do this, the EU has implemented three mechanisms outlined in the Kyoto protocol: emissions trading scheme (ETS), clean development mechanism (CDM) and joint implementation (JI).

In January 2005 the pilot phase known as Phase I of EU ETS was introduced formally. The EU ETS is a cap-and-trade scheme that issues a restricted amount of emission allowances, also known as European Union allowances (EUAs), to companies on an annual basis. Each EUA represents the right to emit 1 metric tonne of carbon dioxide. At the end of each year companies must hold the required

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[2] The first named author is employed by the Royal Bank of Canada. The views expressed here are those of the author and should not be attributed to the Royal Bank of Canada. The second and third named authors work at the School of Business, University College Dublin, Ireland.

amount of emission allowances to meet their emissions over the previous year. The scheme covers firms operating in the power sector, cement and ferrous metal producers and all combustion facilities with a generating capacity of 20 MW, or more. Airlines joined the scheme in January 2012. The ETS allows firms to trade the amount of emission permits that they hold and as a result has applied a market value to this asset. Phase I of the EU ETS ended in December 2007, with Phase II starting in January 2008. Since its inception in 2005 the EU ETS has become the world's largest emissions market. According to PointCarbon (2012), 8 billion metric tonnes of emission allowances were traded on EU ETS in 2011 - a 19% increase compared to 2010 figures. The majority of the trading (over 80%) takes place on the European Climate Exchange (ECX), which was established in 2005.

The introduction of global emission trading markets and their rapid growth resulted in the establishment of emission allowances as a new financial asset. The growth of the carbon markets has mainly been as a result of the involvement of other investors, including hedge funds, pension funds, foundations, and other plan sponsors. These investors have no emission reduction obligations and participate in the carbon markets in order to extend their investment opportunities through diversification. Despite increased interest in carbon markets from both researchers and practitioners the literature on portfolio management with carbon assets is still very limited. Mansanett, Bataller and Pardo (2008) study investment characteristics of EU ETS futures both as a sole investment and as part of a diversified portfolio. The authors investigate the properties of EUA futures prices for Phase I and Phase II of the EU ETS, coupled with energy variables such as Brent and natural gas, as well as equities and bonds. Their main findings indicate that both Phase I and Phase II EUA futures are unattractive as a stand-alone investment and that including CO$_2$ EUA futures in an already diversified portfolio can improve the investment opportunity set. Chevallier (2009) performs mean-variance optimization and analyses efficient frontier for diversified portfolios that include carbon assets. The range of asset classes include equity, fixed income, oil and natural gas, coal and the risk-free asset in the form of the US Treasury bills. The author finds that a diversified portfolio can achieve an annual return of 3% with standard deviation less than 0.06 by including carbon assets.

The common approach used in the literature to analyse the diversification potential of an asset class is to consider two types of portfolios. The first, a standard portfolio would include the 'standard' asset classes such as stocks and bonds. The second, an alternative extends the standard portfolio by adding the new asset class in question. The mean-variance optimization is performed for both portfolio types and the performance of the standard and alternative efficient portfolios is compared. The mean and the covariance matrix of asset returns that are used as inputs for the optimization problem are generally not known and need to be estimated from historical data. The issue of sensitivity of portfolio allocations to the estimation error has been studied by many authors (for example, see Jobson and Korkie (1980) and Michaud (1989)). The main implication of this sensitivity is the poor out-of-sample performance of mean-variance efficient portfolios constructed from sample data. Various robust optimization techniques have been proposed to address this issue. Michaud (1998) develops a bootstrap based resampling mechanism, Jorion (1986) suggests using Bayes-Stein shrinkage estimator for the mean and Ledoit and Wolf (2004b) introduce shrinkage estimator for the covariance matrix. Empirical research conducted by these authors indicates that portfolios constructed using robust methods are better diversified and outperform their sample counterparts.

This paper extends previous research on diversification effects of carbon assets in several ways. First, we examine a much richer portfolio and one that takes account of the research in the portfolio management literature. Second, a detailed statistical analysis of all assets during Phase 1 and 2 is examined. Third, formal sensitivity tests are performed to compare portfolio performance using the Jobson-Korkie test. The remainder of the chapter is organized as follows. Section 2 provides a review of the academic literature on carbon markets and emission allowances, as well as recent developments in the robust portfolio optimization literature. Section 3 outlines the methodology employed to analyse diversification effects of EUA futures, while section 4 describes the data set used for the empirical study and presents the results. Conclusions are provided in section 5.

2. Emissions Trading Literature Review

Price Drivers

The establishment of the new European emission allowances market and its rapid growth led to creation of the new asset class - emissions allowances. Benz and Truck (2009) pointed out the significant differences between emission allowances and equities. They argue that the value of a stock is based on profit expectations of the firm that distributes the shares, while the price for emission allowances is determined by the expected market scarcity caused by the current demand and supply. One important factor is that firms by themselves are able to control market scarcity, and therefore the market price, by their abatement decisions. Activating an abatement measure may have a significant impact on market liquidity and on price dynamics. The authors proposed a more appropriate approach in specifying CO2 emission allowances as a factor of production and drew parallels between emission allowances and commodities.

Benz and Truck (2009) conduct empirical analysis of EUA Phase I spot prices and look at the major price determinants for emission allowances. They categorize the main factors affecting emission allowances prices into (i) policy and regulatory issues and (ii) market fundamentals. Policy and regulatory related price sources have a long-term impact on prices with a rather low probability for an exact forecast. However, changes in policy directives or regulations may also have substantial consequences on the demand, supply and thus short-term price behaviour of emission allowances. Hence, the consequences of changes in regulatory or policy issues may be sudden price jumps, spikes or phases of extreme volatility in allowance prices. Incorporating part (ii), CO2 production depends on a number of factors, such as weather data (temperature, rain fall and wind speed), fuel prices and economic growth. Especially unexpected environmental events and changes in fuel spreads will shock the demand and supply side of CO2 allowances and consequently market prices. Therefore, this source of price uncertainty may have a rather short or medium-term impact on market liquidity of the allowances that possibly increases volatility of the allowance prices. Based on these stylized facts the authors suggest the use of GARCH and Markov switching models to describe emission allowance price dynamics.

Uhrig-Homburg and Wagner (2009) studied the relationship between EUA spot and futures prices for contracts that expire in Phase I. Their analysis demonstrated that market efficiency increased after December 2005 and that spot and futures prices are linked by the cost-of-carry mechanism. Moreover, it was shown that the CO2 futures market leads the price discovery process. Borak et al (2006) conduct an empirical study of EUA prices for spot and futures contracts expiring in both Phase I and Phase II. They found emission allowances price behaviour in the spot and futures market to be substantially different to those of other commodities. Market prices indicate changing dynamics in the term structure and volatility of spot and futures prices. The initial backwardation was replaced by contango with significant convenience yields for the futures contracts maturing in Phase II.

Alberola et al. (2008) conducted econometric analysis of daily EUA spot prices for Phase I. Their model was based on several energy variables such as prices of oil, coal, natural gas and electricity as well as temperature variables. The important factor in their research was to take into account two structural breaks that occurred in April 2006 following the disclosure of verified emissions and in October 2006 when EC announced the restrictions for 2008-2012 allocation. The study provided evidence that within Phase I different fundamentals seemed to co-exist before and after the aforementioned breaks.

This analysis was further extended by Daskalakis et al. (2009) who analysed the effects of banking prohibition between Phase I and Phase II on the spot and inter-phase futures prices. Their empirical analysis suggested that the best approximation of their relationship is obtained by a two-factor futures pricing model which assumes a jump-diffusion for the underlying process and a stochastic, mean reverting convenience yield. Using data from the three main emission exchanges Pownext, Nordpool and ECX the authors found that the prohibition of banking had increased the inter-phase futures prices by about 5% and had induced additional costs to market participants in the order of 1.36 billion euro from June 2005 to July 2007. Finally, Bredin and Muckley (2011) adopted static and recursive versions of the Johansen multivariate cointegration likelihood ratio test to examine how EUA prices are affected by several factors such as energy spreads, European-wide measurements of equity markets, temperatures and production as well as expected fossil fuel prices including coal, natural gas and oil during the 2005 through to the 2009 period. They found evidence of a new pricing regime established in Phase II represented by a cointegration relationship between model variables. This can be seen as an indication of increased efficiency of EU ETS market in Phase II.

Market Efficiency

Daskalakis and Markellos (2008) examined the efficiency of EU ETS market using spot and futures data from the three main exchanges - Powernext, NordPool and ECX. They performed serial correlation analysis and employed variance ratio test to find that EUA returns are serially predictable and reject the random walk hypothesis that shed doubts on weak market efficiency. In addition to that, several technical analysis trading strategies were studied. Such strategies exploit the predictability of EUA price series to create significant risk-adjusted returns. The authors argue that the most plausible explanation for market inefficiency are the restriction on banking between Phase 1 and Phase 2 as well as restrictions on short-selling of EUAs that led to reduction in liquidity.

Boutaba (2009) investigated price transmission between major exchanges under EU ETS. Weekly spot prices from Climex, Powernext, EEX, EEA and Nordpool. The analysis was performed with the help of time series analysis techniques such as unit root tests, cointegration tests, Vector Error Correction models and Granger causality tests. Results showed that the five carbon markets exhibited a reasonable degree of efficiency in both long and short-run. Finally, Bredin, Hyde and Muckley (2011) used ultra-high frequency EUA futures price data from ECX to analyse market micro structure. The vector autoregression (VAR) model was employed to study relationships between trade duration, volatility and volume. The findings indicated significant developments in the market for emissions, further evidence of market efficiency and specific evidence in favour of the sequential information arrival hypothesis.

Portfolio Management

Since the seminal work by Markowitz (1952) the issue of adding new assets and the effects on portfolio performance has received a lot of academic attention. Jensen et al (2000) examined portfolios that can invest in stocks, corporate bonds, Treasury-bills, REITs and the commodity futures over the period 1973 to 1997. They found that, depending upon risk tolerance, commodities should represent anywhere from 5-36% of investors' portfolios. Erb and Harvey (2006) also studied commodity futures in portfolio context. Their analysis showed that a long-only allocation to commodities does not yield equity-like return. On the other hand, they provided evidence that there are benefits to an asset allocation overlay that tactically allocates using commodity futures exposures. The authors examined several trading strategies that use both momentum and the term structure of futures prices. The results suggested that the tactical strategies provide higher average returns and lower risk than a long-only commodity futures exposure.

The literature on portfolio management with carbon assets is still in its infancy. To the best of our knowledge, the first study of EU ETS emission allowances and portfolio management has been completed by Mansanett, Bataller and Pardo (2008). The authors investigated the properties of EUA futures prices for Phase I and the beginning of Phase II. They found that both Phase I and Phase II EUA futures contracts are unattractive as a sole investment due to their negative returns and high volatility. The authors pointed out those investors that took short positions in these contracts assumed high risk but also received high returns. The paper looked at EUA futures in the context of multi-asset portfolio consisted of futures on Dow Jones Euro Stoxx 50, Euro Schatz, Bolb and Bund futures and Brent and Natural Gas futures. Using both historical and risk-adjusted returns the authors found that Phase I and Phase II EUA futures can improve the investment opportunity set for an investor that initially invests in traditional assets such as stocks and fixed income.

A recent study by Chevallier (2009) examined how Phase II EUA futures can be used to manage risk in a portfolio context. This paper extended results of Mansanett, Bataller and Pardo (2008) by performing portfolio optimization on a wider set of asset classes that in addition to equity, fixed income, oil and natural gas, coal and the risk-free asset in the form of US Treasury-Bills. Another innovation in this paper was to include CER credits. The main reason for including CER credits is the additional diversification to a portfolio due to their fungibility with other international ETS other than the EU ETS. Using classical CAPM approach, Chevallier showed that carbon, gas, coal and bonds share the desirable properties in terms of betas to compose a globally diversified portfolio, and that a global portfolio with energy (including carbon), weather, bond, equity risky assets and a riskless assets achieves a level of standard deviation less than 0.06 for an expected return of 3%.

Methodology

The question of how an asset type affects mean-variance characteristics of an already diversified portfolio has been studied extensively. Jensen et al (2000), for example, studied the diversification effects of commodity futures. Amin and Kat (2003) analyzed the diversification effects of including hedge funds. The common approach used in the literature is to consider two types of portfolios. The first portfolio type consists of 'standard' asset classes such as stocks and bonds. The second portfolio type extends the standard portfolio by adding the new asset class in question.

In our case the standard portfolio consists of the following asset classes: European equities, European government and corporate bonds, crude oil, natural gas and non-energy commodities. The extended portfolio also includes Phase 1 or Phase 2 EUA futures. Borak et al (2006) argued that emission allowances is a new commodity type because a company must have allowances for compliance reasons. On the other hand, as Mansanett, Bataller and Pardo (2008) pointed out, there are differences between emission allowances and traditional commodities. Emission allowances are kept in electronic registries and therefore there are no storage costs. Unlike traditional commodities, the companies only need to have sufficient amount of allowances that correspond to their verified emissions for a specific year, in April of the following year (2003/87/EC Directive). In our analysis we follow the approach by Mansanett, Bataller and Pardo (2008) and treat emission allowances as a separate asset class.

For each phase a rolling window optimization is performed. Asset allocations are recalculated on a quarterly basis using historical returns within rolling 6 month window. During each optimization process the following portfolio types are constructed:
Portfolio 1 - Minimum variance (MV) Portfolio based on sample covariance matrix
Portfolio 2 - MV Portfolio using Bayes-Stein shrinkage estimator for covariance matrix
Portfolio 3 - Tangency Portfolio based on sample mean and sample covariance matrix
Portfolio 4 - Tangency Portfolio estimated using Bayes-Stein shrinkage estimator for the mean and sample covariance matrix
Portfolio 5 - Tangency Portfolio estimated using sample mean and shrinkage estimator for covariance matrix
Portfolio 6 - Tangency Portfolio based on Bayes-Stein shrinkage estimator for the mean and shrinkage estimator for covariance matrix
Portfolio 7 - Naive Portfolio that uses the same allocation for all assets

Both the standard and the extended portfolio are constructed for each of the above types. Portfolio optimization is performed with short-selling allowed.[3] The inclusion of Portfolio 7, a naive portfolio, is informed by the findings of De Miguel et al., (2009). To answer the question of how EUA futures affect already diversified portfolios, we compare the performance of standard and extended portfolios using the Jobson-Korkie test.

3. Data and Results

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[3] For space considerations we have not reported the results when short sales constraints are imposed.

Data

To study the effects of adding EUA futures contracts to an already diversified portfolio we consider the following standard asset classes: equities, government and corporate bonds, oil, gas and non-energy commodities. The list below contains details of indexes we use to proxy each asset class.

Phase I EUA Futures - EUA Futures front contracts (December 2005 contracts are used to represent Phase I EUA Futures prices in 2005, December 2006 contracts are used in 2006, etc.; switch takes place in the third week in December of each year)
Phase II EUA Futures - December 2008 and December 2009 EUA Futures Contracts (switch takes place in the third week in December 2007)
Stocks - Dow Jones Euro Stoxx 50 Index
Government Bonds - IBOXX Euro Sovereign All Maturities Price Index
Corporate Bonds - IBOXX Euro Corporate AAA Rated All Maturities Price Index
Crude Oil Bonds - Dow Jones UBS Energy (DJAIGEN) Sub-Index
Natural Gas - Dow Jones UBS Energy (DJAIGEN) Sub-Index
Non-Energy Commodities - Dow Jones UBS Ex. Energy (DJAIGXE) Sub-Index
Risk-Free Asset - Euribor 1 Month rate

The EUA futures prices are quoted in Euro. EUA futures prices have been obtained from ECX. All other price series have been sourced from DataStream. The sample dataset for analysing Phase I EUA futures contains daily price series and covers the period from April 22nd 2005 until December 17th 2007. The dataset for analysing Phase II EUA futures contains daily prices which run from April 22nd 2005 until July 14th 2008.

Table 1 EU ETS Phase 1 - Summary Statistics

	Mean %	Std Dev %	Sharpe	Skew	Kurt	JB Stats
Phase I EUA Futures	-94	170.11	-0.57	-3.08	76.78	149363.82**
Stocks	14.98	14.53	0.81	-0.32	4.01	38.63**
Crude Oil	0.29	27.86	-0.1	0.13	3.29	3.9
Natural Gas	-40.49	49.53	-0.88	0.33	4.98	118.51*
Non-Energy Commod.	8.7	14.5	0.38	-0.23	4.01	33.17**
Government Bonds	-2.6	3.08	-1.86	-0.03	3	0.12
Corporate Bonds	-2.72	1.89	-3.1	-0.08	3.55	8.54**

*Note. *(**) represents significance at the 5 %(1%) level.*

Table 1 above contains summary statistics for the Phase I dataset. As can be seen, EUA futures delivered a negative annual return of -94% and have by far the highest annual standard deviation of 170.11% compared to all other assets under consideration. The high volatility can be explained by the sharp falls in the EUA futures prices due to over allocation of allowances in the beginning of Phase I. Negative return is not surprising either and can be attributed to the prohibition of banking between Phase I and Phase II. In addition, EUA futures returns have the lowest negative skewness and the highest kurtosis. The only two assets with the positive Sharpe ratios are stocks and non-energy related commodities. Unsurprisingly, government and corporate bonds have the lowest volatility. Natural gas futures had the second worst return after EUA futures and the second highest volatility. Note that return distributions of all assets in this dataset are non-normal as indicated by the Jarque-Bera test statistics.

Taken together the summary statistics for Phase I dataset indicates the unattractive nature of EUA futures contracts on an individual basis. Although, as Mansanett, Bataller and Pardo (2008) point out, investors who took short positions in this asset assumed high risk but obtained positive return. Table

2 below contains summary statistics for the dataset we use to analyse portfolio performance in Phase II. Compared to Phase I, EUA futures in Phase II were considerably less volatile with standard deviation of 46.34% and delivered a high annual return of 15.79%. Phase II EUA futures returns have negative skewness and the highest kurtosis. Natural gas has the worst return and the highest volatility. Return distributions of all assets in Phase II except for Government Bonds are non-normal as confirmed by the significant Jarque-Bera test statistics. Although Phase II EUA futures are highly volatile, they also delivered high returns. This could make Phase II EUA futures attractive to investors who are risk takers. Compared to Phase I, the return volatility of Phase II EUA futures has reduced significantly from 170.11% to 46.34%.

Table 2 EU ETS Phase 2 - Summary Statistics

	Mean %	Std Dev %	Sharpe	Skew	Kurt	JB Stats
Phase II EUA Futures	15.79	46.34	0.27	-1.45	19.3	9074**
Stocks	2.44	16.77	-0.05	-0.26	6.92	515.8**
Crude Oil	12.73	28.47	0.33	0.13	3.37	6.39*
Natural Gas	-26.68	47.27	-0.64	0.22	5.09	149.59**
Non-Energy Commod.	7.99	15.18	0.3	-0.42	4.36	84.25**
Government Bonds	-2.71	3.39	-1.79	0	3.34	3.56
Corporate Bonds	-2.77	2.28	-2.68	-0.06	4.51	75.22**

*Note. *(**) represents significance at the 5 %(1%) level*

Correlation Analysis

It is well known that one of the main conditions for an asset to increase the investor opportunity set in a portfolio context is that it has low or negative correlation with the other assets already contained in the portfolio. Table 3 below contains correlation coefficients for all assets in Phase I. The EUA futures have positive, though quite low, statistically significant correlations with crude oil, and corporate bonds. Correlations with other asset returns are close to zero and not statistically significant. Stocks are positively correlated with non-energy commodities and negatively correlated with fixed income securities. All commodities, including crude oil, natural gas and non-energy commodity futures are positively correlated. As expected, government and corporate bond indices are highly correlated.

Table 3: EU ETS Phase 1 - Correlations

	EUA Futures	Stocks	Crude Oil	Natural Gas	Non-Energy Commod.	Government Bonds
Stocks	-0.01					
Crude Oil	0.10**	0.09*				
Natural Gas	0.06	0.02	0.43**			
Non-Energy Commod.	0.05	0.29**	0.37**	0.16**		
Government Bonds	0.05	-0.25**	-0.05	0.04	-0.16**	
Corporate bonds	0.08*	-0.30**	-0.04	0.04	-0.16**	0.95**

*Note. *(**) represents significance at the 5 %(1%) level.*

Table 4: EU ETS Phase 2 – Correlations

	EUA Futures	Stocks	Crude Oil	Natural Gas	Non-Energy Commod.	Government Bonds
Stocks	0.02					
Crude Oil	0.16**	0.09**				
Natural Gas	0.12**	0.04	0.44**			
Non-Energy Commod.	0.14**	0.30**	0.41**	0.20**		
Government Bonds	-0.02	-0.34**	-0.05	0.02	-0.16**	
Corporate bonds	0	-0.39**	-0.05	0.02	-0.15**	0.95**

*Note. *(**) represents significance at the 5 %(1%) level.*

Table 4 above reports correlation coefficients for all assets in Phase II. The EUA futures have positive and statistically significant correlations with crude oil, natural gas and non-energy commodity futures. Correlations with other assets are close to zero and are not statistically significant. Stocks have positive statistically significant correlations with crude oil and non-energy commodity futures and negative correlations with fixed income assets. Again, all commodities, including crude oil, Natural Gas and non-energy commodity futures are positively correlated. Non-energy commodity futures are negatively correlated with both corporate and government bonds. As was the case in Phase I, government and corporate bond indexes are highly correlated.

These results suggest that both Phase I and Phase II EUA futures are probably not a good diversification asset in a portfolio with energy contracts although it could be a good diversification asset in a portfolio made up of traditional investments such as stocks and bonds. These findings are consistent with correlation analysis results reported by Mansanett, Bataller and Pardo (2008).

Optimal Portfolio Analysis

In this section optimal allocations are analysed for extended minimum variance and tangency portfolios. Formal performance comparison of standard and extended portfolios is conducted with the help of the Jobson-Korkie test. For each portfolio type the main performance characteristics such as return, risk and Sharpe are reported. In addition to that, the higher moments of return distribution as well as results of Jarque-Bera normality test are presented for each portfolio type.

EU ETS Phase 1

Table 5 below reports descriptive statistics for the returns of extended portfolios constructed using seven different strategies outlined in section 3. The classical tangency portfolio is the only one that has a positive return. In terms of risk adjusted excess returns as illustrated by Sharpe ratios, the tangency portfolio does not provide any benefits. All other portfolios cannot outperform the risk-free asset and have negative Sharpe ratios. The naive portfolio has the lowest return and the highest volatility. Return distributions of all portfolio types are negatively skewed and leptokurtic. The hypothesis of return distribution normality is rejected at the 1% significance level.

Table 5: EU ETS Phase 1 - Optimal Extended Portfolio Statistics

	Mean %	Std Dev %	Sharpe	Skew	Kurt	JB Stats
Portfolio 1	-2.16	1.73	-0.2	-0.15	3.57	8.62*
Portfolio 2	-1.61	3.99	-0.08	-0.15	6.48	260.99**
Portfolio 3	2.16	16.96	0	-0.41	6.24	239.86**
Portfolio 4	-2.72	21.36	-0.02	-0.29	8.98	775.49**
Portfolio 5	-1.34	18.47	-0.02	-0.35	8.04	557.30**
Portfolio 6	-6.17	23.15	-0.03	-0.23	10.61	1251.36**
Portfolio 7	-42.75	27.7	-1.67	-1.63	47.13	42252.38**

*Note. *(**) represents significance at the 5 %(1%) level.*

Table 6: EU ETS Phase 1 - Jobson-Korkie Test Results

	Portfolio 1	Portfolio 2	Portfolio 3	Portfolio 4	Portfolio 5	Portfolio 6	Portfolio 7
Portfolio 1	-1.4	-3.62**	-3.42**	-3.14**	-3.31**	-3.06**	-2.06*
Portfolio 2	2.73**	1.44	-2.07*	-1.41	-1.84	-1.27	0.18
Portfolio 3	3.30**	2.38*	-0.42	0.49	-0.05	0.68	1.87
Portfolio 4	3.11**	2.04*	-0.87	-0.07	-0.6	0.15	1.57
Portfolio 5	3.12**	2.11*	-0.88	0.01	-0.57	0.23	1.62
Portfolio 6	2.98**	1.85	-1.11	-0.4	-0.87	-0.19	1.38
Portfolio 7	1.17	-0.21	-2.56*	-2.24*	-2.44*	-2.14*	-1.07

*Note. This table reports results of Jobson-Korkie test comparing performance of extended (rows) and standard (columns) optimal portfolio strategies for various optimal portfolios in Phase 1. *(**) represents significance at the 5 %(1%) level.*

Table 6 above reports results of Jobson-Korkie test comparing performance of extended (rows) and standard (columns) optimal portfolio strategies various optimal portfolios. For example, the Jobson-Korkie test statistic comparing performance on the extended minimum variance portfolio and the standard minimum variance portfolio is -1.40. The negative value, although statistically insignificant, means that standard minimum variance portfolio outperform the extended one. The Jobson-Korkie test statistic comparing performance on the extended minimum variance portfolio with shrunk covariance matrix and its standard counterpart is 1.44. Although statistically insignificant, the value is positive, indicating that the extended portfolio outperforms the standard one. The diagonal elements in table 6 are of most interest to us, as they characterize performance differences between two portfolios due to inclusion of EUA futures into the asset mix. Note that when the same strategy for extended and standard portfolios is compared the test does not detect any statistically significant differences. The table shows that standard minimum variance portfolio is outperformed by the extended minimum variance and tangency portfolios that are constructed using shrinkage estimator. This, however, cannot be attributed to the inclusion of EUA futures in the extended portfolios.

EU ETS Phase 2

Table 7 below contains descriptive statistics for the returns of extended portfolios in Phase II. As can be observed, all tangency portfolios have positive Sharpe ratios. Minimum variance and naive portfolios have negative returns and hence negative Sharpe ratios. Classical tangency portfolio delivered the highest return and also has the highest Sharpe ratio. All minimum variance, naive and the robust mean and covariance matrix tangency portfolios have negative skewness, whereas other tangency portfolios have positively skewed return distributions. All portfolio types are leptokurtic and non-normal.

Table 7: EU ETS Phase 2 - Optimal Extended Portfolio Statistics

	Mean %	Std Dev %	Sharpe	Skew	Kurt	JB Stats
Portfolio 1	-3.29	1.96	-3.51	-0.39	4.52	78.92**
Portfolio 2	-2.31	3.25	-1.81	-0.37	6.01	258.84**
Portfolio 3	17.36	20.05	0.69	0.2	5.56	180.66**
Portfolio 4	8.95	22.19	0.24	0.06	4.98	106.16**
Portfolio 5	14.48	20.67	0.53	0.17	5.27	141.14**
Portfolio 6	5.54	23.63	0.08	-0.03	5.32	144.55**
Portfolio 7	-3.81	13.15	-0.56	-0.44	4.96	125.30**

*Note. *(**) represents significance at the 5 %(1%) level.*

Table 8: EU ETS Phase 2 - Jobson-Korkie Test Results

	Portfolio 1	Portfolio 2	Portfolio 3	Portfolio 4	Portfolio 5	Portfolio 6	Portfolio 7
Portfolio 1	-0.27	-3.88**	-5.00**	-4.69**	-4.91**	-4.60**	-3.42**
Portfolio 2	3.43**	2.11*	-3.82**	-3.27**	-3.66**	-3.12**	-1.62
Portfolio 3	4.90**	4.11**	-0.32	0.64	-0.01	0.85	2.49*
Portfolio 4	4.46**	3.54**	-1.46	-0.57	-1.26	-0.33	1.86
Portfolio 5	4.74**	3.91**	-0.8	0.23	-0.51	0.47	2.29*
Portfolio 6	4.29**	3.31**	-1.75	-0.98	-1.6	-0.77	1.6
Portfolio 7	3.71**	2.67**	-2.10*	-1.64	-1.97*	-1.51	0.84

*Note. This table reports results of Jobson-Korkie test comparing performance of extended (rows) and standard (columns) optimal portfolio strategies for various optimal portfolios in Phase 2. *(**) represents significance at the 5 %(1%) level.*

Table 8 above reports results of Jobson-Korkie test comparing performance of extended (rows) and standard (columns) optimal portfolio strategies in Phase II. Unlike the case of Phase I, the Jobson-Korkie test comparing performance of minimum variance portfolio with shrunk covariance matrix is statistically significant. For this strategy extended portfolio outperforms the corresponding standard one.

4. Discussion of Results and Market Implications

The findings of this study indicate that, in the context of Phase II, risk taking investors could invest in the EUA futures. The Phase II sample used in this study extends the analogous sample in the work of Mansanett, Bataller and Pardo (2008) by approximately six months in which EUA futures prices grew substantially. A much more rigorous range of portfolio examinations and sensitivity tests are adopted here. Results in this study show that Phase I EUA futures have positive statistically significant correlation with only crude oil and corporate bonds, while Phase II EUA futures have positive statistically significant correlations with all commodities and close zero correlations with stocks and bonds. The main focus of this study has been on the out-of-sample performance of the diversified portfolios with and without EUA futures. In Phase 2, the volatility has decreased and EUA futures delivered a high return. This can be explained by the banking ability between Phase II and the future phases of EU ETS. Another reason for the reduced volatility could be due to the increased efficiency of carbon market in Phase II, as illustrated in Bredin and Muckley (2011). As a result, performance improvements have been identified in the diversified portfolios composed of long only positions. Allocations to Phase II contracts are however relatively small in these portfolios due to high volatility of the EUA future prices compared to standard assets.

The Phase II results indicate a level of consistency with Chevallier (2009) who found that an extended portfolio including Phase II EUA futures achieved a standard deviation of less than 0.06 for an expected return of around 3%. While the Phase I results are consistent with findings of Mansanett, Bataller and Pardo (2008), the implications of the extended sample are particularly noteworthy given the evidence of long only allocations. The findings reported here are significant given the recent results on the market development in the carbon finance area. Specifically, Bredin and Muckley (2011) found evidence of a new pricing regime established in Phase II represented by a cointegration relationship between energy spreads, equities, temperatures and production as well as expected fossil fuel prices including coal, natural gas and oil. This can be seen as an indication of increased efficiency of EU ETS market in Phase II.

5. Conclusions

As part of the Kyoto Protocol the European Union has committed to reduce its greenhouse gas emissions to eight percent below 1990 levels by 2012. In January 2005 the European Union emissions trading scheme (EU ETS) was instigated in order to comply with the Kyoto commitments. The scheme issues a restricted amount of emission allowances to companies on an annual basis and allows firms to trade the amount of emission permits that they hold. Phase I of the EU ETS runs from January 2005 to December 2007 and Phase II, which also coincides with the first compliance period of the Kyoto Protocol, is from January 2008 to December 2012.

The rapid growth of emission trading market has led to the establishment of emission allowances as a new financial asset. The new market has attracted new participants, such as hedge funds, pension funds, foundations, and other plan sponsors. These investors have no emission reduction obligations and participate in the carbon markets in order to extend their investment opportunities through diversification.

This study analysed performance characteristics of EUA futures for Phase I and II of EU ETS as a stand-alone investment, as well as in a portfolio context. Phase I EUA futures have negative returns and extremely high standard deviation. As a result, these assets are unattractive as a sole investment.

Phase II EUA futures delivered high return which is offset by high volatility. The risk adjusted excess return measured by Sharpe ratio is the third highest after crude oil and non-energy commodities in the Phase II dataset. Furthermore, Paolella and Taschini (2008) highlight that the ultimate aim of this scheme (as well as the US CAAA-Title IV scheme) must be to create an environment where there is a scarcity of allowances which will lead to mean reversion around an upward trend in prices. This could make Phase II EUA futures attractive to investors who are risk takers.

Correlation analysis has been conducted to identify diversification benefits of adding Phase I and II EUA futures to the already diversified portfolio that contains equities, Euro denominated corporate and government bonds, crude oil, natural gas and non-energy commodities. Phase I EUA futures have significant positive correlations with crude oil and corporate bonds. Other correlations are statistically insignificant and close to zero. Phase II EUA futures have statistically positive correlations with crude oil, natural gas and non-energy commodities. As a result, both Phase I and Phase II EUA futures would provide limited diversification opportunities in a portfolio that already has commodity futures but there are potential diversification benefits in a portfolio made up of traditional investments such as stocks and bonds. The out-of-sample performance of standard and extended portfolios for various optimization strategies has been compared. In particular, the analysis has focused on the minimum variance and tangency portfolios with allocations computed from sample data as well as using shrinkage estimators. Sharpe ratio has been used to measure risk-adjusted portfolio performance. Formal sensitivity tests have been conducted using Jobson-Korkie test statistics for comparing Sharpe ratios.

Allocations to Phase I EUA futures in the optimal portfolios are small and there is no statistically significant difference in the risk adjusted excess returns between standard and extended portfolios. No statistically significant performance improvement was observed when Phase II EUA futures were added to the tangency portfolios. Collectively, these results provide new evidence into the benefits of introducing EUA futures for diversification purposes in portfolio management. In particular, this applies to the contracts with maturities in Phase II of EU ETS. Low correlations with standard asset classes allows for more efficient portfolio management with EUA futures by eliminating idiosyncratic risk in a diversified portfolio of assets. This is a further indication of the increased efficiency and a maturing market.

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