Università Commerciale Luigi Bocconi
IEFE
Istituto di Economia e Politica dell'Energia e dell'Ambiente

ISSN 1973-0381

WORKING PAPER SERIES

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Working Paper n.19

April 2009

www.iefe.unibocconi.it

Carbon allowances as inputs or financial assets: lesson learned from the Pilot Phase of the EU-ETS[*]

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April 15, 2009

Abstract

This paper provides an updated state of art in the literature on carbon permits as inputs and financial assets. Analyses refer to the operation of the European market for allowances in the Pilot Phase. Results are particular intriguing as they posit the bases for future assessments.

1 Introduction

The interest for market mechanisms which lead a cost-efficient reduction of environmental externalities has increased since early 1990s. With the failure of a Community-wide carbon tax system and the signature of the Kyoto Protocol (1997), marketable allowances has become the key tool. From then on, academics have discussed the compelling properties of permit systems both theoretically and, more recently, empirically.

The EU Directive 2003/87/EC has established a scheme for trading greenhouse gas emissions within the Community (henceforth, EU-ETS). This tool should contribute to achieve a cost-effective reduction of the environmental externalities caused by greenhouse gases. To date, three regulatory periods have been put in place. The Pilot Phase covered the period 2005-2007. Since January 2008 the scheme has entered Phase II, which will last in 2012. Phase III has been recently approved (Directive 2008/101/EC) and will regulate emissions in 2013-2020. Much has been written so far on the EU-ETS in Phase I, despite the first period was meant to be a learning process. Among others, Mansanet-Bataller *et al.* (2008), Convery (2009), Convery *et al.* (2008) and Ellerman *et al.* (2008) have argumented about the environmental and economic performance of the Pilot Phase of the system. Despite the progresses made, it is still unclear to which extent carbon allowances in the Pilot Phase (and from then on) should be treated as a production input

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or a financial asset. This paper addresses these issues and provides a very updated state of the art. We rely on the most interesting empirical studies which have been tested on Phase I of the EU-ETS. The aim of our survey is twofold. It is intended to shed some light on the determinants as well as in the complex - *stochastic* - behaviour of CO_2 prices in the years 2005-2007. Second, it discusses the possibility of extending the results for the Pilot Phase to subsequent stages. In particular we question whether the carbon price drivers identified so far (Mansanet-Bataller *et al.*, 2007; Alberola *et al.* 2008, 2009a, 2009b) may still hold in Phase II.

Results are as follows. According to Rickels *et al.*, 2007, Mansanet-Bataller *et al.* (2007) and Alberola *et al.* (2008; 2009a; 2009b), energy prices - and input prices (i.e. brent, coal and gas prices) in particular - are the main determinant of EUA prices. Weather variables are usually not statistically significant; technological parameters, although statistically significant, are negligible thus confirming the slight abatement effort which has occurred in the Pilot Phase. The organization of carbon markets is the main responsible for intra-period breaks' such as those in April 2006 (after the certified disclosure of current emission paths) and in April 2007 (when the market, realizing the long positions of regulated installations, officialized the collapse of carbon prices). This strand of literature provides one main finding suitable for future assessments: it is possible to test the maturity of carbon markets using the explanatory power of energy prices.

Regarding the financial approach to EUAs, the most interesting forcasts have been provided by Benz *et al.* (2008), Paolella *et al.* (2007), Seifert *et al.* (2008) and Daskalakis *et al.* (2007). The complexity of the EUA market, which comes forth the interaction among multiple sources of uncertainty, has led to the adoption of heterogeneous approaches (AR-GARCH, regime-switching, brownian augmented with jumps, GAt-GARCH, etc.) and differentaited evaluation criteria (MAE, MSE, L, AIC, BIC, etc.). As a consequence, the most likely econometric specification has not been identified. The allowances traded in 2005-2007 echoe inputs more than financial assets. However this is mainly due to the immaturity of the carbon market. Moreover financial models, by pointing out the linkage between the performance of the spot market for allowances and the regulatory framework, have formalized the unsuitability of Pilot Phase's assessments for Phase II and III.

The paper is organized as follows. Section 2 discusses the regulatory framework and the most relevant indicators. The industrial economic approach to marketable allowances is in Section 3. Focusing on CO_2 permits as production inputs, we discuss the determinants of carbon prices from the theoretical point of view. The empirical counterpart is in Section 4. Results for the financial strand of literature are in Section 5, where we review the most suitable stochastic patterns to replicate the behaviour of carbon prices. Section 6 presents the convenience yield approach to carbon prices. Section 7 reviews the main findings and concludes.

2 The EU-ETS in the Pilot Phase

This Section provides some insights on the institutional background to which the surveied literature refers.[1] The Pilot Phase of the EU-ETS was intended by the EU Commission as a learning period and the regulatory framework was designed accordingly. The sectoral coverage has been defined by taking into account economic (market liquidity, concentration, etc.) and administrative criteria (i.e. measuring, reporting and verification costs). This in turn has led the inclusion of combustion facilities with a thermal input greater than 20 MW, oil refineries, coke ovens, iron and steel plants as well as factories making cement, glass, lime, bricks, ceramics, pulp and paper. In 2005-2007, regulated installations accounted for 11000 units and were responsible for about 50% of the carbon emissions - 41% of the greenhouse gas emissions - in the Community. After the initial grandfathering, EU allowances (henceforth, EUA) becomes tradable. Since April 2005, carbon permits have been exchanged on several platforms: OTC (over-the-counter), spot (i.e. NordPool and European Energy Exchange - EEX) and futures markets (i.e. NordPool, Powernext and European Climate Exchange).[2] The former is the most liquid, but price data are confidentials. Among the remaining trading platforms where EUAs are traded, the most liquid is the European Climate Exchange (ECX). By the early operation of the system, transactions have grown sharply: 270 Mt CO_2 in 2005, 1100 Mt CO_2 in 2006 and 2000 Mt CO_2 in 2007 (World Bank, 2008). Despite the increased liquidity which is a prerequisite to market maturity, EUA's spot prices have remained unstable: 10€/t CO_2 in January 2005, 22€/t CO_2 since June 2005, 13€/t CO_2 in the second half of 2006 and below 1€/t CO_2 since June 2007 (ECX, 2008).

A more detailled picture of trading activities and the carbon price paths in 2005-2007 is in Figure 1. Academics have recognised that price jumps are correlated to information disclosure. The evidenced over allocation of allowances is the main cause of the three jumps in the daily returns occurred in April/May 2006 which were over 25%. Jointly with intra-phase banking restrictions (and therefore expiry of Period I's allowances in December 2007), this over allocation is also responsible of the collapse of carbon prices since 2007. Regarding the statistic properties of EUA spot prices, we notice that the peak spot price in 2005, 2006 and 2007 is some 80%, 360% and 430% higher than the minimum. The overall distribution of returns is leptokurtic with a long left tail which indicates negative skweness. Unit root tests performed show that log-returns appear to be stationary (Mills *et al.*, 2008).

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[1] Mansanet-Bataller *et al.* (2008), Convery (2009), Convery *et al.* (2008) and Ellerman *et al.* (2008) have argumented the main lessons learned from the Pilot Phase of the EU-ETS.

[2] Notwithstanding differences in pooled values, the homogeneity of the commodity traded at each trading platform has led to convergence in prices and therefore to similar statistic properties.

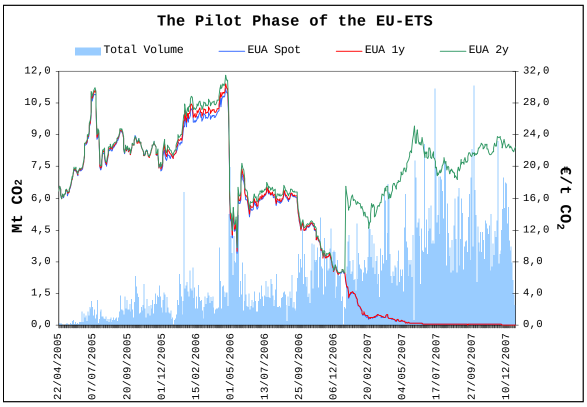

Figure 1. The EU-ETS in 2005-2007: trading volumes (OTC excl.) and permit prices. Source: ECX, 2008

3 Carbon allowances as new production inputs

This Section reviews the industrial economic approach to carbon allowances. According to academics, which have started investigating the issue by the early stages of the EU directive 2003/87/EC, several factors should affect the price of EUA (Springer, 2003; Christiansen *et al.,* 2005). Results are heterogeneous and reflect the diverse methodologies (and perspectives) adopted.[3] When arguing about the determinants of EUA prices, existing contributions have distinguished among *institutional factors*, *market structure* and *exogenous factors.* Let's discuss each category in short. The first group consists of co-dependent levels of regulation (i.e. international, European and national), each of which responsibles - to various extents - of actual carbon price paths. The core determinants at the world wide level are the tightness of international caps on carbon emissions, the breadth of the Kyoto Protocol (Nordhaus *et al.*, 1999; Nordhaus, 2001), and the link between flexible mechanisms (i.e. Certified Emission Reduction Units, Emission Reduction Units and International Tradable Certificates) and EUAs. At the Community level, the main determinants of EUA prices are the tightness of European targets (Burden Sharing Agreement, 1998); sectoral coverage (as it affects the liquidity of carbon markets); inclusion (or the exclusion) of temporal restrictions (Springer *et al.*, 2004); and evolution of environmental regulation. At the national level, the key driver of carbon prices is the National Allocation Plan which aims at regulating sectoral and plants' emissions. To date, applications have ignored the effect institutional factors at the world-wide level. The motive is the following. We have noticed in the introduction that the surveyed models are applied to the EU-ETS in the Pilot Phase. In 2005-2007, the European

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[3] Theoretical models which analyses the determinants of CO_2 prices can be parted into five categories, depending on the approach adopted: (1) integrated assessment models, (2) computable general equilibrium models, (3) emission trading models, (4) Neo-Keynesian macroeconomic models and (5) energy system models. For a more detailed description of each category see Springer (2003).

scheme is regional in scope and unique in the application (no-linkages with flexible mechanisms); hence, it is by no mean misleading the exclusion of the world-wide regulatory framework.

Regarding *market structure*, the literature has distinguished between macroeconomic (i.e. GDP and economic growth) and microeconomic (i.e. input - energy - prices, input substitutability, availability and costs of abatement technologies) determinants for carbon prices.[4] Particular attention has been deserved to microeconomics variables. In fact, according to Kanen (2006), Christiansen *et al.* (2005), Bunn *et al.* (2007) and Convery *et al.* (2007), energy prices are the most important drivers of carbon prices. Regarding EUA and electricity prices, they are expected to be correlated as a higher demand for power would lead to higher emissions, thus increasing the tightness of the carbon constraint. But input (i.e. brent, natural gas, coal) and EUA prices are expected to be correlated too. The logic is as follows. Currently, the power sector accounts for some 39% of the European CO_2 emissions. The carbon intensity of the industry crucially depends on the technology used. Gas-fired units are less carbon intensive than the coal-fired counterparts. Higher gas (brent) prices, by reducing the profitability of gas-fired plants, may increase the share of energy produced by coal-fired technologies. This in turn would cause an increase in carbon emissions. The carbon constraint would become more binding, leading an upward pressure on EUA prices. The reverse applies to carbon prices. Higher carbon prices, by reducing the profitability of coal-fired plants, may increase the share of energy produced by gas-fired technologies, which favours a reduction of emissions and thus of EUA prices.

The category *exogenous factors* mainly refers to climate variables (i.e. temperatures, especially the extreme ones, precipitations, clouds and windspeed).[5] By influencing energy demand, weather conditions may have an indirect impact on EUAs. Several studies have highlighted the effect of climate on energy prices. In particular, Li *et al.* (1995) and Springer (2003) have indicated a non-linear relationship between temperatures and electricity demand and confirmed the intuition that only increases and decreases beyond certain thresholds should be taken into account.

Section 4 details how the determinants discussed above have been captured by the industrial literature on the Pilot Phase of the EU-ETS.

4 The empirics on carbon allowances as production inputs

This Section surveys the empirics from industrial organization to carbon price determinants by the models of Mansanet-Bataller *et al.* (2007) and Alberola *et al.* (2008, 2009a, 2009b).

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[4] The argument has been investigated by Kainuma *et al.* (1999), Van der Mensbrugghe (1998), Burniaux (2000), McKibbin *et al.* (1999) Ciorba *et al.* (2001), Springer *et al.* (2004), Bahn *et al.* (1999, 2001), Kanudia *et al.* (1998) Zhang et al. (1998), Grubb *et al.* (1993), Sijm *et al.* (2000), Kanen (2006), Bunn *et al.* (2007) and Convery *et al.* (2007).

[5] Further details about the issue are in Kainuma *et al.* (1999) and Ciorba *et al.* (2001).

4.1 When energy prices and climate variables matter

As noticed above, energy prices are expected to be the most important driver of EUA prices. Weather conditions should follow. Mansanet-Bataller *et al.* (2007) has been the first providing an empirical assessment of theoretical expectations. Regarding the methodology, the authors adopt a multivariate regression OLS model corrected by the the Newey-West covariance matrix, in order to effectively deal with the issues of heteroskedasticity and autocorrelation.[6] In particular, they have implemented the estimation models (with dynamics in energy variables) in (1)

$$r_{c,t} = \left\{ \begin{array}{c} \alpha_j + \beta_j(L)r_{g,t} + \delta_j(L)r_{b,t} + \\ \phi_j(L)r_{cl,t} + \gamma_j Ratio_t + \eta_j D_{\max,t} + \varphi_j D_{\min,t} \end{array} \right\} + A + \varepsilon_t \tag{1}$$

where A takes into account changes in climate regressors and it is given by

$$\kappa_j Tm_t + \mu_j D_{T\max,t} + \theta_j D_{T\min,t} + \nu_j RR_t + \varpi_j D_{RR\max,t} + \omega_j D_{RR\min,t}$$

$$\text{or}$$

$$\kappa_j Tm_t^E + \mu_j D_{T\max,t}^E + \theta_j D_{T\min,t}^E$$

Variables are defined as follows. $r_{\cdot,t}$ denotes the series of log-returns. It is constructed as $r_{\cdot,t} = \ln(p_{\cdot,t}/p_{\cdot,t-1})$, where $p_{i,t}$ is the price level (at time t) of the i-th variable. The downscript t indicates the time interval (i.e. 1^{st} January- 30^{th} November 2005), and the downscripts c, g, b and cl refer to carbon allowances, gas, brent and coal respectively. The *European Carbon Index* is used as a proxy for carbon spot prices (€/ton eq.CO_2). Daily forward prices traded at the International Petroleum Exchange (IPE) are used for brent ($/barrel) and gas prices (GBP/therm). Concerning daily forward prices for coal ($/metric ton), the database used is the one published by Tradition Financial Services (TFS).[7] The regressor *Ratio* is obtained as the quotient between the gas price change and the coal price change - formally $Ratio = r_{g,t}/r_{cl,t}$ - and, according to the authors, it should explain the effect of coal-to-gas switching (i.e. the effect of short-term abatement options in the power industry). $D_{\max}$ and $D_{\min}$ are dummy variables that rule out extreme CO_2 price changes.[8] L is the lag operator. ε_t is the error term of the regression. Remaining variables refer to climate factors and are similar to those in Boudoukh *et al.* (2007). Tm_t is the index series of mean air temperature in Germany. $D_{T\max,t}$ and $D_{T\min,t}$ are dummies related to extremely high and low temperatures respectively. RR_t is the total precipitation index for Germany. Finally, $D_{RR\max,t}$ and $D_{RR\min,t}$ are dummies capturing the effect of extremely rainy and dry days, respectively. The

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[6] The relevant price series (i.e. allowances price, gas, brent and power prices) do present a unit-root and are stationarized by taking the first log-difference.

[7] Quotations have been converted into euros using the daily exchange rate data available from the European Central Bank.

[8] Considering the market rather immature, the authors have estimated the model controlling for extreme movements in carbon price series. The CO_2 price changes considered are the three highest (on 21/03/05, 22/03/05 and 04/04/05) and lowest (on 21/03/05, 22/03/05 and 04/04/05) of the sample.

superscript E is used to indicate the take out of the series of German weather and the take in of the European's.

Mansanet-Bataller *et al.* (2007)'s results are consistent with theoretic intuitions and market agents' perceptions. As a general remark, energy variables are the main determinants of EUA prices, while weather data are almost irrelevant.[9] Among energy variables, brent and natural gas price changes are the key drivers. In contrast, neither the price level of the most intensive emission source (i.e. coal) nor the regressor Ratio, measuring the coal-to-gas switching effect, are statistically significant.

Although the model is an important step towards the complete understanding of the determinants of EUA prices, it undergoes two main drawbacks. First, institutional decisions are missing. Second, selected data series may yield misleading results. Let's consider each argument separately. It is our opinion that institutional factors have been excluded from this preliminary investigation due to either shortages in data or regulatory credibility. The sample period in Mansanet-Bataller *et al.* (2007) runs from the formal launch of the EU-ETS, 1^{st} January 2005, to the 30^{th} November 2005. However the overall cap stringency became appreciable by the early months of 2006, that is when counterfactual emissions were certified. Moreover since January 2005, major sources of regulatory uncertainty have been resolved. At this purpose, we would recall that at the entering into force of the Pilot Phase of the EU-ETS, National Allocation Plans were established, inter-phase and inter-tools linkages were rejected, and both sector coverage and firm-specific permit holdings were fixed.

Regarding the data series, the authors have ignored whatever start-up effect. Despite the entering into force of the EU-ETS, the first trade in an organized market for carbon emissions took place on the 11^{th} February 2005 and it was a future contract in NordPool. Similarly, the first spot contract has been traded on the European Energy Exchange in March 2005. Since June 2005 the European carbon markets have remained almost illiquid; therefore including the early months of 2005 is, at least, misleading. A further issue in data series is on weather variables. Concerning climate regressors, we question both the choice of German indicators[10] and the usage of daily climate variables. In fact, as the impact of climate variables on carbon prices is indirect (it is captured by energy demand) and the operation of carbon markets is annual, weather variables may affect carbon prices only if they alter energy demand expectations.

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[9] Except for extreme temperatures, $D_{T\max,t}$ and $D_{T\min,t}$, which are both positive and statistically significant. Coherently with Li *et al.* (1995) and Springer (2003), extreme events, by prompting energy market demand (due to air conditioning in the summer and/or home heating in the winter), increase carbon emissions and are expected to lead an upward pressure on permits' prices.

[10] The presumption that the initial permit holding - Germany holds some 24% of EUAs - may be used as a proxy for carbon shortages.

4.2 The role of market structure and institutions

According to Mansanet-Bataller *et al.* (2007), climate and energy factors explain some 50% of real CO_2 price patterns. However, in light of the shortcomings discussed above (i.e. absent/misleading regressors), these results might be questionable, which is the issue in Alberola *et al.* (2008). Despite the similarity in the argument investigated (i.e. factors influencing carbon prices) and the approach used (i.e. multivariate analysis), the specification performed by Alberola *et al.* (2008) differs from Mansanet-Bataller *et al.* (2007) substantially. As a preliminary remark, the protracted experience in EUA trading has allowed the extension of the time series to the entire Pilot Phase of the EU-ETS, which lasted two years. In addition, recognizing the start up role of the first semester and the deceptive performance of the last one – motivated by non-binding caps (on aggregate) and inter-phase banking restrictions -, Alberola *et al.* (2008) has opted for excluding data earlier than July, 1^{st} 2005 and later than April, 30^{th} 2007. Moreover, the authors have identified proxies to bring into the analysis policy factors. Previous empirical studies (i.e. Mansanet-Bataller *et al.*, 2007; Rickels *et al.*, 2007) have focused on the impact of energy prices and weather conditions on carbon markets (we have just recalled the motives which have led this simplification). However, given the artificial origin of carbon markets, moving apart of institutional frameworks is unacceptable. Furthermore, alternative databases are used. Powernext daily EUA spot prices replace the *European Carbon Index*. The *European Temperatures Index*[11] is used instead of Deutscher Wetterdienst data. To internalize the effect of changes in expectations, Alberola *et al.* (2008) have relied on futures Month Ahead energy prices. Finally, to provide a better understanding of the impact of traditional factors (i.e. climate, fuels and power prices) and to take in the effect of abatement options, Alberola *et al.* (2008) have considered additional regressors and alternative specifications.

The methodology is consistent with Mansanet-Bataller *et al.* (2007). The estimation technique used is the OLS with the Newey-West correction, given the presence of heteroskedasticity in the time series data detected by the White test. The estimation models are

$$r_{c,t} = \left\{ \begin{array}{c} \alpha_i + \beta_i(L) r_{c,t} + \chi_i break_1 + \delta_i break_2 + \\ + \phi_i(L) r_{b,t} + \varphi_i(L) r_{g,t} + \gamma_i(L) r_{cl,t} + \eta_i(L) switch_t + \\ + \iota_i(L) r_{e,t} + \kappa_i(L) clean\_dark_t + \lambda_i(L) clean\_spark_t \end{array} \right\} + A + \varepsilon_{i,t} \tag{2}$$

where matrix A takes into account carbon in climate regressors and it is given by

$$A = \left\{ \begin{array}{c} \Theta_i Temp + \mu_i Temp5 + \nu_i Temp95 \\ \text{or} \\ o_i Jul05 + \theta_i Win06 + \vartheta_i Jul06 + \rho_i Sepoct06 + \sigma_i Win07 \end{array} \right\}.$$

t is the sample period under consideration (1^{st} July 2005 - 30^{th} April 2007), i corresponds either to the full period, the main periods, or the sub-periods (i.e. $i = \{$ "full period", "before compliance

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[11] Weather variables are constructed by using daily data on Spain, France, Germany and the UK.

break", "after compliance break","June06 - Oct06","Oct06 - April07"}). Returns are defined as in Mansanet-Bataller *et al.* (2007). They are assessed as $r_{\cdot,t} = \ln(p_{\cdot,t}/p_{\cdot,t-1})$, where $p_{i,t}$ is the price level (at time t) of the i-th variable. The downscripts c, g, b, cl and e refer to carbon allowances, gas, brent, coal and electricity respectively. The daily forward price traded at the International Petroleum Exchange (IPE) ($/barrel[12]) is used for brent. The daily future Month Ahead price (€/MWh) negotiated on Zerbrugge Hub is used for natural gas. The daily future Month Ahead price CIF ARA (€/ton) is used for coal, and the contract of futures Month Ahead Base (€/MWh) is used for electricity. The variables $break_1$ and $break_2$ are the dummies that characterize the periods after the structural changes which have occurred on April 2006 and October 2006, respectively. To take into account of abatement options for power producers and relative fuel prices, three specific regressors have been included: $clean\_dark_t$, $clean\_spark_t$ and $switch_t$. The former is obtained as the difference between the price of electricity at peak hours and the price of coal used to generate that electricity (€/MWh). Similarly, the second is the difference between the daily price of electricity at peak-load hours and the price of natural gas used to generate that electricity (€/MWh). The dark spread is the marginal profit of an operative coal-fired power unit. And, similarly the spark spread is the marginal profit by a gas-fired energy producer. In a carbon constrained environment, such marginal profit depends on the price of allowances (as marginal production costs depend on EUA prices). Recalling that gas-fired units are more environmental-friendly (but less cost-efficient) than coal-plants, it is possible to define an EUA price such that gas and coal-fired units are equally profitable. This price level is the *switching price.* It measures the profitability of coal-to-gas switching and is used to derive the proxy $switch_t$ for abatement costs. For stabilization purposes, Helfand *et al.* (2006)'s methodology has been applied to energy prices.[13] Regarding the the matrix of climate regressors, the specification in the first model specification is consistent with Mansanet-Bataller *et al.* (2007). $Temp$ is the EU temperature index, $Temp5$ and $Temp95$ are dummies for extremely cold and hot days respectively. In a second specification, weather regressors are interaction variables obtained as cross-products between weather events and extreme deviations:[14] $Jul05$ is the dummy which refers to the hot July 2005, $Win06$ the cold winter 2006, $Jul06$ the hot July 2006, $Sepoct06$ the hotter September/October 2006 and $Win07$ the milder winter 2007. Except for $Jul05$, which is national in scope (i.e. Spain), climate dummies apply to the EU. Finally, L indicates the lag operator.

Results are consistent with theoretic expectations and previous empirical assessments (i.e. Mansanet-Bataller *et al.*, 2007 and Rickels *et al.*, 2007). In the full sample period EUA prices are determined by energy prices and policy regressors. Among energy variables, both input (i.e. $r_{g,t}$, $r_{b,t}$ and $r_{cl,t}$), input related (i.e. $clean\_dark$ and $clean\_spark$) and output (i.e. $r_{e,t}$) regressors are statisticaly significant. $clean\_dark$ is above $clean\_spark$ during Phase I of the EU-ETS,

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[12] $ have been converted into € as in Mansanet- Bataller *et al.* (2007).

[13] See Helfand *et al.* (2006) for more details about the "one-step ahead" forecast errors methodology.

[14] See Alberola *et al.* (2008) for further details on the computation mode.

which means that despite environmental regulation coal-fired power units are more profitable than gas-fired', thus contributing to the increase in the demand for carbon allowances. The coefficients of $r_{b,t}$ and $r_{g,t}$ are not statistically different from zero. The abatement proxy is negligible. Concerning regulatory dummies, only $break_1$ is statistically significant. The finding is confirmed by the fact that while the discovery of counterfactual emissions has led a 4 days lasting collapse of EUA prices on April 2006, in conjuctiong of the second break (October 2006) the reduction was less intense and more lengthy. Independently of the specification applied, temperature variables are not statistically significant, due to either the non-linearity or the indirect relationship between climate and EUA prices.

Interestingly, Alberola *et al.* (2008)'s econometric specification explains one-third of carbon price patterns. Sub-periods investigations make clear that policy proxies are the main driver of EUA prices from June 2005 to April 2006, while energy fundamentals govern post-compliance break trajectories. These findings are tempting. Beside confirming the artificial nature of the European carbon market, they signal an increased maturity of the system by mid-2006.[15]

Alberola *et al.* (2008) have improved Mansanet-Bataller *et al.* (2007)'s tecnique. We think that the adding of policy determinants has yielded a twofold advantage over previous empirical assessments. Not only Alberola *et al.* (2008) is suitable to investigate the statistic significance of institutional facts, but it is appropriate to study the effect of changes in the policy agenda upon traditional – energy and climate – regressors (i.e. it is suitable to conduct robustness investigations). Concerning market structure, Alberola *et al.* (2008)'s regressors differ from Mansanet-Bataller *et al.* (2007) substantially. *Ratio* is neglected, while power log-returns and new measures for abatement options (*clean_dark* and *clean_spark*) are filled in. We rest sceptical with this choice as it may lead an overlapping of regressors and is unsuitable to replicate the technological heterogeneity of EU power markets. Power supply systems show a quite composite structure from the technological point of view. They take in plants differing in either the primary energy used (i.e. coal, gas, renewables, nuclear, etc.) or in the technological solution adopted (i.e. combined cycle gas turbines versus steam cycles). Moreover, as Mansanet-Bataller *et al.* (2007), Alberola *et al.* (2008) has excluded further relevant indexes (i.e. sectorial production, efficiency, etc.) and moved apart of the most suitable regressor for modelling expectations (i.e. EUA forward prices). Together with energy prices, Alberola *et al.* (2008) share with Mansanet-Bataller *et al.* (2007) the focus on weather variables. Two kinds of dummies are used to take into account the effect of extreme weather conditions (i.e. either extremely cold/hot days or monthly extremes). The influence of precipitation, wind speed and other climatic conditions on energy demand is left for future studies due to lack of data availability at the EU level. Again, we question the role played by climate variables.

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[15] Scholars use the reaction of EUA prices to energy price fundamentals as a measure of carbon market's maturity.

A further step in market structure: disentangling the effect of industrial production. The role of market structure is further investigated in Alberola *et al.* (2009a) and (2009b). As we noticed above, EUA prices may be affected by the economic activity of the full sectors covered by the EU-ETS. Industries, which have resulted in higher (lower) production growth over 2005-2007 than their baseline projections, will be net buyers (sellers) of carbon allowances. The relationship has been formalized in Alberola *et al.* (2009a) where paper (for the sector paper and pulp), metal (as proxy for iron and steel), coke oven, chemical, glass, cement and power (i.e. heating from electricity and gas) industrial production indexes are considered. Data have been collected from Eurostat at two different levels, EU-27 and Country specific,[16] and re-sampled to get daily frequencies. The key results are as follows. At the EU-level, the combustion sector is the main driver in the full sample period, but it loses its leadership in favor of coke oven if investigations are restricted to the post compliance period (i.e. April 2006 – June 2007). When reverting to Country-level assessments, further production indexes become relevant. The performance of the paper and the glass industries are statistically significant in Germany and Italy, respectively. Alberola *et al.* (2009b) also shows that the effect of sectoral production on EUA prices is non-linear: changes in industrial emissions depend on numerous factors. Although several studies have investigated the argument (Sanstad *et al.*, 1998; Liaskas *et al.*, 2000; Diakoulaki *et al.*, 2007), Alberola *et al.* (2009b) is the sole application coherent with the EU-ETS's framework. Performing the analysis the authors demonstrate that both variations in production (i.e. peaks) and yearly net positions (i.e. sectoral compliance) are relevant drivers of CO_2 prices.

Policy uncertainty and information disclosure. Finally, the effect of policy uncertainty on carbon prices is in Alberola *et al.* (2009b). The authors have introduced a proxy to capture the impact of information revelation.[17] According to Alberola *et al.* (2009b), information disclosure is statistically significant for 2005, not for 2006. Therefore, the allowance squeeze probability did constitute a carbon price driver in 2005 but not in 2006. The intuition is as follows. Awaiting short positions of the installations covered by the EU-ETS, both compliant agents and speculators have bought EUAs on March-April 2006. By converse no transactions have occurred on March-April 2007, since operators expected the emission cap to be non-binding (i.e. the initial permits holding exceeded expected counterfactual emissions).

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[16] France, Germany, Italy, Spain and the UK as these countries account for some three quarters of permit holdings during the Pilot Phase.

[17] This proxy has been constructed by cross-multiplying two variables. The former reflects the allowance squeeze probability and computes at time t the number of days remaining before the yearly compliance event (30^{th} April). The latter is a dummy that takes the value of one fifteen days prior to the official yearly verified emissions announcement, and is zero otherwise.

5 Carbon permits as financial assets

Alongside the industrial strand of literature, several financial studies have arisen aimed at modeling the behaviour of carbon emission allowance prices. The logic for financial forecasts has been threefold. Carbon returns are not correlated with the returns of traditional financial assets. As the new commodity may increase the diversification of a financial portfolio and reduce the overall investment risk, a deeper investigation of its properties is needed. Second, since January 2005 the EU-ETS has experienced an upsurge of derivative markets. The profitability of contracts depends on the spread between forward and spot prices at the execution date, which has spurred forecasts on the expected price of the underlying assets. Finally, carbon price forcasts are the main drivers of (medium and long-term) investments by regulated sectors.

Notwithstanding the short-run perspective of this paper, we have not disregarded studies which have been intended to model the forward price of EUAs. In fact, due to the banking restriction, these prices are particularly suitable to provide indications for the performance of the EU-ETS in Phase II (2008-2012). The most interesting forcasts have been provided by Benz *et al.* (2008), Paolella *et al.* (2007), Seifert *et al.* (2008) and Daskalakis *et al.* (2007). Henceforth we discuss each model and the related findings.

Benz *et al.* (2008) have suggested the use of AR-GARCH and regime-switching models to model the stochastic behaviour of EUA spot prices.[18] These econometric assessments have been based on daily EUA prices (3^{rd} January 2005 - 30^{th} December 2005) published by Spectron, which is one of the main brokers in the energy trading industry. Data are stationarized using log-returns. The empirical analyses has comprised in-sample and out-of-sample forecasting evaluations. Results have been examined against different benchmark models - *id est* AR(1) and simple normal distributions - and may be summarized as follow. Markov regime-switching models have provided the best in-sample fit. Confirming the start up role of early stages, two regimes have elapsed: a rather quiet period (January-June 2005) - *low volatility in returns* - and a noisy one (July-December 2005) - *high volatility in returns.* Regarding out-of-sample forecasting analyses, although the simple normal distribution has provided the smallest Mean Absolute Error (MAE) and Mean Squared Error (MSE), the best interval forecasts have been obtained by using markov regime-switching models while the AR-GARCH models have outperformed the alternative assessments with respect to density forecasts. Notice that for risk management purposes, either density or interval forecasts are more relevant than both MAE and MSE since traders and brokers are more interested in

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[18] AR-GARCH models describe the behaviour of the underlying commodity by a unique stochastic process with conditional variance. Possibly the most important aspect of these models is the recognition that volatility can be estimated based on historical data. By contrary, Markov regime-switching models explain the behaviour of the underlying product by multiple (and different) stochastic processes each referring to a phase (regimes). These models are particularly suitable for consecutive price jumps and extreme returns. For a detailed technical specification on AR-GARCH models see Bollerslev (1986) and Taylor (1986), while for technical specifications on Markov regime-switching models see Goldfeld *et al.* (1973) and Hamilton (1989,1990).

predicting intervals for future price movements than in simple point assessments.

Paolella *et al.* (2007) have proposed particular GARCH-type structure to describe the stochastic spot price behaviours of EUA: the GAt-GARCH[19] model. The database used is Powernext and includes 454 observations (since 25 th June 2005). The series have been stationarized through the use of log-returns. Coherently with Benz *et al.* (2008), the examination has included in-sample and out-of-sample measures. The performance of GAt-GARCH has been compared to the one of benchmark models (i.e. a battery of GARCH models)[20]. The econometric specification that has provided the best in-sample estimates, when measured by the likelihood-based goodness-of-fit criteria, has been the GAt-GARCH. Concerning the out-of-sample estimates, the suggested model has outperformed the alternatives at the 1% level of confidence. However at lower levels of confidence, none of the models considered has provided adequate VAR predictions. The presumption of constant stochastic generating process, which is one major hypothesis in GAt-GARCH and in the benchmark models, is unsuitable to replicate the instability couched in the rather new CO_2 European emission rights market. To overcome this drawback, Paolella *et al.* (2007) have suggested the use of parametric GARCH models, but the actual fit has been left for future researches.

Seifert *et al.* (2008) differ slightly from the previous contributions as the authors explicit a theoretical stochastic finite horizon equilibrium model which incorporates the main fatures of the EU-ETS. Since the EUA market presents large jumps in prices due to its immaturity condition, it appears difficult to study the carbon price behaviour grounding on time series data. Moreover a theoetical model, by indentify the general properties of the European carbon market, is suitable to forecast Phase II patterns. The solution can be derived only for a special case and shows that spot prices remain bounded between 0 and the penalty cost. Moreover, the volatility of the EUA prices goes to 0 as they are close to the price bounds. Within a stochastic environment the expected abatements and the banking levels result to be higher than in a deterministic world: the presence of uncertainty requires to the compliant agents to be prepared against possible future losses. Finally, since the modeled prices show a very large volatility increase at the end of each trading period, Seifert *et al.* (2008) suggest to eliminate the inter-phase banking restriction in order to allow a smoother transition between trading periods and therefore to obtain a more efficient market.

Daskalakis *et al.* (2007) present the first attempt to forecast both spot and forward CO_2 prices. Unlike the continuity showed by the spot prices, futures prices time series appears to be divided into two parts. The provision of the inter-phase EUA fully banking restriction has caused a break in the forward prices time series. This has led different behaviours (and characteristics) of Phase I and Phase II futures prices. First and foremost, the forward price in Phase I has resulted highly correlated with spot prices trend since the value of the MSE referring to the contracts Dec-06 and Dec-07 (i.e. those contracts expiring in December 2006 and 2007) is 0.3765 and 0.4925 re-

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[19] Generalized asymmetric t distribution GARCH.

[20] The benchmark models considered are: normal-GARCH, t-GARCH, $S_{\alpha,0}$-GARCH, $S_{\alpha,\beta}$-GARCH, MixN(3,2).

spectively. On the contrary, the high value of the MSE for the contracts Dec-08 and Dec-09 008 (i.e. those contracts expiring in December 2008 and 2009) have attested their divergence from the current spot price (10.4700 and 10.6565 respectively). Secondly, the average value of the Phase II futures price has been about three times above the same for Phase I contracts. Morevoer, the variance of the intra-phase forward returns has been much higher than the inter-phase futures (75% for Dec-06, 49% for Dec-08 and Dec-09). Finally, the return of Phase I futures' have shown a leptokurtic distribution with a negative skweness (similar to spot prices). However, the distribution of the returns in Phase II has been leptokurtic but with a positive skweness. Because of the statistic differences between short and long-term products, especially between the spot and the inter-phase futures contracts, alternative econometric specifications have been suggested. The short-run behaviour of carbon prices has been modeled by a geometric brownian motion process augmented by jumps. Derivative products have been modeled using a standard cost-of-carry relationship characterized by the presence of the jump diffusion stochastic equation of the spot prices plus a mean reverting process for the convenience yield.[21] Data have been collected by Powernext, NordPool and ECX (25th October 2005 – 28th December 2007). Series have been stationarized by log-returns. In-sample and out-of sample analyses have been conducted. The suitability of the suggested models has been compared to alternative stochastic configurations[22] with respect to log-likelihood and BIC criteria. The geometric brownian motion process has provided the best goodness-of-fit measures for both in and out-of sample analyses. Similar concerns have applied to long-term forecasts where cost-of-carry models have outperformed alternative specifications.

The main caracteristic of the financial literature analysed so far is the heterogeneity of approaches adopted. An important concern follows. The large variety of models considered (AR-GARCH, regime-switching, brownian augmented with jumps, GAt-GARCH, etc.) and the different evaluation criteria used (MAE, MSE, L, AIC, BIC, etc.) impede the identification of the most suitable econometric specification. However, it is useful in that it attests the difficulties encountered in analysing carbon markets due to the presence of several sources of uncertainty. As noticed by Benz *et al.* (2006), *there are several price determinants of CO_2 allowances which have stochastic behaviours (the changes of policy directives and regulations, the weather data, fuel prices, economic and sectorial growth, etc.). In particular, unexpected environmental events and sudden large variations in the fuels preads represent the most affecting sources of EUA price uncertainty. As a consequence, CO_2 allowances prices and returns present a stochastic behaviour characterized by*

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[21] Under the risk neutral measure, the stochastic specification for the spot prices within the cost-of-carry relation is equivalent to the one suggested in the short-term analyses. The convenience yield instead is assumed to follow, consitently with the previous commodity literature (Schwartz, 1997 and Hilliard *et al.*, 1998) a mean reverting stochastic process.

[22] The benchmark is constituted by the following configurations: Geometric Brownian motion process (GBMP), Mean Reverting Square-root process (MRSRP), Mean Reverting Logarithmic process (MRLP), Constant Elasticity of Variance (CEV) and Mean Reverting Square-root process augmented by jumps (MRSRPJ).

price jumps, spikes as well as phases of high volatility and heteroskedasticity in returns. To our opinion the most interesting contribution is Daskalakis *et al.* (2007), which have investigated the joint behaviour of spot and forward prices. This study has revealed that the findings on Phase I carbon (spot) prices are unlikely to hold for Phase II since the regulatory framework differ. Secondly, it has tested the possibility of using a cost-of-carry model to identify the price of carbon derivatives properly, thus opening the way to the research on convenience yields (see Section 6).

6 On carbon price determinants and expectations

A common feature in the literature on the determinants of carbon prices is the presumption that insitutional, market and climate factors are the main responsible for EUA prices. Within this Section, we wonder whether (and up to which extent) expectations and changes in expectations may constitute other factors which affect carbon price trends. Since forward CO_2 prices are suitable proxies for expectations, the effect of information discovery may be investigated throughout the relationship between the spot and the forward price of allowances. Depending on the difference between forward and spot prices, commodity markets may be characterized by *backwardation* and/or *contango*.[23] Another feature typical of commodity markets is the presence of the Samuelson effect, which consists in a *declining term structure in the volatility of futures prices as maturity increases.* According to Samuelson (1965), expectations of investors in long-term contracts are poorly affected by current changes since the latter are perceived as contingent. Otherwise, when the expiration date of the futures is proximal, investors become more sensitive to information disclosure and the price volatility of forwards increases. Borak *et al.* (2006) notice that each issue (i.e. spot-forward price differentials and time-to-maturity effects) is described by factor pricing models[24] in a more appropriate manner than by financial stock pricing. A compelling feature of cost-of-carry models is the inclusion of a term - the convenience yield - which indicates the benefits (or drawbacks) of holding inventories. Before discussing the results of factor pricing models, we briefly illustrate the derivation of the convenience yield.

The convenience yield. The convenience yield is derived in no-arbitrage contexts such as those of cost-of-carry models, which consider hedging strategies consisting of holding contracts' assets until maturity. Hereby, the long position in the underlying is funded by a short position in the money market account. Differences between current spot prices and forward prices are explained by the interest foregone when storing a commodity, warehousing costs and the convenience yield

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[23] At time t the futures prices, $F_{t,T}$, of a commodity with delivery in T can be greater, equal or less than both the current the spot price of the asset, S_t, and the expected spot price at delivery in T, $E_t(S_T)$. Futures markets exhibit *backwardation* if $F_{t,T} \leq S_t$, *normal backwardation* if $F_{t,T} \leq E_t(S_T)$. Futures markets exibit *contango* if $F_{t,T} > S_t$, *normal contango* if $F_{t,T} > E_t(S_T)$.

[24] We use factor pricing, no-arbitrage and cost-of-carry as if they were synonyms for the same of group of models.

on inventory. The latter is derived explicitly when no-arbitrage is stated (Pindyck, 2001). Assume we hold one unit of emission rights at time t and we hold it untill T. The storage cost is zero. Hence, by holding the emission right until maturity we get the stochastic return in (3):

$$S_T - S_t + \psi(T-t) \tag{3}$$

where S_i is the spot price at time i and $\psi(T-t)$ denotes the convenience yield. Assume that at the same time we take a short position with delivery in T. This contract pays back

$$F_{t,T} - S_T$$

where $F_{i,j}$ is the price of the contract signed at time i with delivery at j. Note that there is no risk involved in the transaction. As the total return is non-stochastic, it should equal the risk-free rate for the period $T-t$ times the current spot price of the emission right. Formally

$$S_T - S_t + \psi(T-t) + F_{t,T} - S_T = \left[e^{r(T-t)} - 1\right] S_t \tag{4}$$

and solving for $\psi(T-t)$ we get

$$\psi(T-t) = S_t e^{r(T-t)} - F_{t,T}. \tag{5}$$

Therefore the convenience yield obtained from holding a commodity is similar to the dividend get from holding a company's stock. It represents the privilege of holding a unit of inventory. According to Pindyck (2001) the spot price of a commodity is similar to the price of a stock: as the price of a stock can be regarded as the present value of the expected future flow of dividends, the price of a commodity is the present value of the expected future flow of convenience yields.[25]

Results for factor pricing models. To date, three models have investigated the convenience yield in EUA markets: Borak *et al.* (2006), Uhrig-Homburg *et al.* (2007) and Milunovich *et al.* (2007). We review each of them separately.

Borak *et al.* (2006) have been the first examining the correlations between spot and futures contracts, the volatility term structure, and the convenience yields in carbon markets. Major results are as follows. By contradicting the Samuelson effect, correlations between spot and futures prices decrease with time to maturity. The term structure of prices shows significant changes through time. And since April 2006, the market has changed from initial *backwardation* to *contango*. The authors, investigating the convenience yields and its heteroschedasticity further, find that a two-factor model using current spot price levels and their volatility as explanatory variables explains a

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[25] Note that in markets where the commodity is non-storable (e.g. electricity) the no-arbitrage fails. If the commodity is perishable, there is no possibility of obtaining a risk-free position by buying the commodity in the spot market and selling in the futures market. However the problem may be circumvented. Further details are in Eydeland *et al.* (1999) and Lucia *et al.* (2002).

high fraction of observed patterns. A major drawback in this model, which has been overcame by later analyses, is the neglection of inter-period banking restrictions.

Uhrig-Homburg *et al.* (2007), by expliciting inter-phase banking restrictions, have demonstrated that *contango* during the pre-Kyoto Phase is due to carbon markets' immaturity and it does not extend to Phase II. The banking restriction prevents the cost-of-carry approach from working across the different Phases. The analyses based on an estimated VECM model show also that the EUA future market is the one that leads the price discovery process. This is mainly due to the higher liquidity of the futures market than the one of the spot market. Hence, in order to consider a reliable EUA price signal market operators should focus their attention on the futures price behviours and dynamics.

Milunovich *et al.* (2007) have performed a cointegration analysis of spot and futures EUA prices in order to understand whether their relationship may be replicated throughout a cost-of-carry model. The authors confirm Uhrig-Homburg *et al.* (2007) findings: cost-of-carry models are unsitable for the Pilot Phase[26] and may not be applied to the second period due to inter-phase banking restrictions. Moreover, by investigating the causality between spot and futures prices through the Granger causality tests, the authors have found that there is bi-directionality Granger causality between spot and futures prices. According to Milunovich *et al.* (2007), this can be interpreted as evidence that the price discovery process occurs in both the spot and futures market. Notice that this result is in contrast to the one of Uhrig-Homburg *et al.* (2007), who find that the price discovery process is led by the futures prices.

7 Summary of main findings and final remarks

This paper provides the most updated state of art in the empirical literature on carbon permits as inputs and financial assets. This survey is particularly interesting, from one side, as it complements traditional assessments on the effectiveness and cost-efficiency of the Pilot Phase of the EU-ETS[27] and, from the other, as it is the first attempt to organize the contributions on carbon permits as production inputs and financial assets extensively.

The Industrial Organization's approach has deserved attention to the determinants of EUA prices and distinguished *institutional factors*, *market structure* and *exogenous variables.* Besides confirming theoretical presumptions and market players' perceptions, this strand of research has stressed the impact of regulation upon the early performance of the EU-ETS. Although energy prices (i.e. brent, natural gas and coal prices) will be the key driver of EUAs in the mid-run (i.e. after the carbon market has attained adequate maturity), due to the fictitious origin of this

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[26] Neither the relationship between spot prices and futures contracts with delivery in December 2006 nor the one with futures expiring in December 2007 are consistent with a cost-of-carry model.

[27] A detailed review is in Mansanet-Bataller *et al.* (2008), Convery (2009), Convery *et al.* (2008) and Ellerman *et al.* (2008).

trading platform, institutional factors are the main responsible for the performance in the Pilot Phase. Over-allocation and inter-phase banking restrictions have led the collapse of carbon values in 2007. As a further remark, the IO literature - *implicitly* - suggests to use the explanatory power of energy prices as a proxy for assessing the maturity of carbon markets.

Alongside the industrial strand of literature, several financial studies have arisen aimed at modeling the stochastic behavior of EUA prices. The large variety of models considered (AR-GARCH, regime-switching, brownian augmented with jumps, GAt-GARCH, etc.) and the different evaluation criteria used (MAE, MSE, L, AIC, BIC, etc.) have impeded the identification of the most likely specification. Despite this drawback, the financial literature has provided two main contributions to the analyses of carbon markets. First, it has formalized the exposure of the EU-ETS to several sources of uncertainty. Second, by pointing out the linkage between the performance in the spot market for allowances and the regulatory framework, it has – *implicitly* – recognized the unsuitability of current assessments (which are related to the Pilot Phase of the EU-ETS) as guidelines for the future operation of the EU-ETS (i.e. Phase II and III).

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