Banking and Borrowing in the EU ETS: An Econometric Appraisal of the 2005-2007 Intertemporal Market

Emilie Alberola* and Julien Chevallier† ‡

April 30, 2009

Abstract

This article critically examines the EU ETS intertemporal market during its Phase I (2005-2007). We test the Hotelling rule as a key element of a competitive equilibrium to validate whether allowance prices rise at the same rate as the interest rate. Including readily observable characteristics of the EU ETS such as the presence of one endogenous structural break and the influence of other energy markets shocks, we argue the inter-period ban on banking undermines the ability of the EU ETS to provide efficient price signalling. We also find a significant relationship between allowance price changes and the expected scarcity of allowances approximated by the Ellerman-Parsons ratio. Finally, our results show evidence of institutional learning by market participants.

JEL Codes: Q28, Q52, Q58

Keywords: Emissions trading, Banking, EU ETS, Hotelling rule

*Mission Climat Caisse des Dépôts, Paris, France. emilie.alberola@caissedesdepots.fr

†University of London, Imperial College of Science, Technology and Medicine, South Kensington Campus, SW7 2AZ London, UK. j.chevallier@imperial.ac.uk

‡Helpful comments were received from seminar participants at the 2007 Envecon Applied Environmental Economics Conference, the 2007 Augustin Cournot Doctoral Days, and the XII. Spring Meeting for Young Economists. The views expressed herein are strictly those of the authors, and do not engage the responsibility of the institutions they are affiliated with. The usual disclaimer applies.

1 Introduction

This article aims at characterizing the dynamic efficiency of the intertemporal market on the European Union Emission Trading Scheme (EU ETS) during the first period 2005-2007. A fundamental statement on emissions trading is that allowances trading is efficient over time only if banking and borrowing are authorized under certainty (Rubin (1996)) and under uncertainty (Schennach (2000)). With such provisions, market prices will reflect opportunity costs which will lead to an efficient choice of abatement measures (Schleich *et al.* (2006)). Each year, when abatement together with endowment of emission allowances are above emissions levels, regulated agents may *bank* surplus allowances for potential later use. Conversely, if regulated agents do not abate enough to cover their emissions level with their actual endowment, they may *borrow* allowances from future allocations. By allowing agents to arbitrate between actual and expected abatement costs over specific periods, banking and borrowing allowances form a complementary dimension of flexibility where agents can trade allowances not only spatially but also through time. The most prominent example of the key role of such provisions is the success[1] of the US Acid Rain Program where banking has been a major feature of this emissions trading (Ellerman *et al.* (2000)).

Prices develop differently in the following two cases. If inter-period banking is allowed, it is reasonable to expect that allowance price changes do not exceed Hotelling's rule, rising at the market rate of interest[2]. If inter-period banking is restricted, lower Phase I prices and higher Phase II prices are ex-

[1] The notion of success may be approximated by various effects (pre-existing regulatory environment, technology innovation and diffusion, reduction of regulatory uncertainty, aggregate cost savings, etc) but we will focus on the efficiency of the permits price, i.e. its ability to reflect current information on spot and future prices.

[2] If participants have complete information and emission targets are known. Hotelling (1931) shows that in an efficient exploitation of an exhaustible resource, the percentage change in net-price per unit of time should be equal to the discount rate in order to maximize the present value of the resource capital over the extraction period. Otherwise, arbitrage between periods is possible and the allowance price path will lead to non socially desirable outcomes such as a concentration of emissions on early periods (Kling & Rubin (1997)). Note that if borrowing is allowed, then the allowance price follows the Hotelling rule for exhaustible resources; if borrowing is forbidden, then the allowance price rises at a rate *inferior* to the interest rate.

pected. The former result is due to the validity of allowances which is shorter than the time horizon required by investors. The latter is due to increased allowance scarcity compared to full inter-period banking.

The European Union Allowances (EUA) price path for the first and second periods seem to match the case of the ban on banking. Beginning at 8 € on January 1st 2005, EUA prices increased to around 30 € in July 2005, fluctuated during the six following months in the range from 20 € to 25 €, then to 30 € until the end of April. On May 15th 2006, the release of 2005 verified emissions data had a depressive effect on EUA prices as shown by the sharp break in the price of all maturities of EUAs in Figure 1. Those data and subsequent updates revealed that verified emissions were about 80 million tons or 4% lower than the amount of allowances distributed to installations for 2005 emissions (Buchner & Ellerman (2007)). As most of the price adjustment occurred within four days, the EU ETS is now sending two price signals responding to different dynamics. First period prices are declining towards zero, whereas second period prices are increasing to levels up to 20 € primarily due to institutional factors disclosed by the European Commission which has reaffirmed its will to enforce tighter targets in Phase II.

Among the main explanations of low allowance prices towards the end of Phase I, previous literature identifies over-allocation concerns, early abatement efforts in 2005 due to high allowance prices, and possibly decreasing abatement costs in 2006 due to abnormal temperatures and switching from coal- to gas-fired electricity in a context of falling natural gas prices compared to coal. Therefore, a thorough analysis of banking and borrowing provisions appears necessary to disentangle those effects on allowance price changes.

Within the first period 2005-2007, participants are expected to use unrestricted banking and borrowing. Based on this assumption, we test in an empirical approach whether the EUA spot price pattern is consistent with a competitive equilibrium in the intertemporal market where banking and borrowing provisions are allowed. Schennach (2000)'s theoretical model of the intertemporal permits market applied by Helfand *et al.* (2006) to the SO_2 market guides our empirical analysis. We conduct a test of the Hotelling rule to validate whether EUA prices follow the interest rate over time. Besides, we use the Ellerman & Parsons (2006) ratio (EPR)[3] to *(i)* approximate the scarcity of EUAs as perceived by market participants by the end of the first period, and *(ii)* test whether the EUA spot price pattern reacts to the scarcity of this environmental policy.

Including readily observable characteristics of the EU ETS such as the presence of one endogenous structural break and the correlation with other energy markets (brent and natural gas), our results show a significant relationship between the EPR and EUA price changes. We also reject the Hotelling rule and argue that the inter-period ban on banking undermines the ability of the EU ETS to provide efficient price signalling. Finally, we find evidence of institutional learning among market participants.

The remainder of the article is organized as follows. Section 2 describes the theoretical framework from which we derive our estimation strategy. Section 3 explicits our econometric specification to test the Hotelling rule. Section 4 summarizes the data used. Section 5 provides a discussion of the results. Section 6 concludes.

2 Economic Modeling

The model estimated is based on two articles by Schennach (2000) and Slade & Thille (1997). It was first applied on the US SO_2 market by Helfand *et al.* (2006).

2.1 Schennach (2000)

First, Schennach (2000) studies the banking behavior of regulated industrials in the Acid Rain Program and implicitly the behavior of spot prices in a stochastic, continous-time, infinite horizon model for allowance allocation, use and storage. Under certainty, the model predicts that the CO_2 price path would increase smoothly at the rate of interest according to the Hotelling

[3] Briefly defined as the December 2007 maturity allowance price over the december 2008 maturity allowance price plus a 40 € penalty for non compliance.

rule. Under uncertainty, the optimization program of risk-neutral agents is modelled as follows:

$$\begin{cases} \min_{e_t} \left\{ E_0 \left[\int_0^{\infty} e^{-\mu t} c_t(\epsilon_t - e_t) dt \right] \right\} \\ \dot{S}_t = Y_t - e_t \\ S_t \geq 0 \end{cases}$$

with $E(t)$ a Von Neumann-Morgenstern expected utility function, e_t the emissions level after abatement, ϵ_t the counterfactual emissions level, $a_t = \epsilon_t - e_t$ the total amount of abatement by all firms at time t, $c_t(a_t)$ the minimum total cost incurred by all firms to abate a_t, Y_t the total amount of allowances distributed to agents, S_t the number of allowances in the bank at time t, r the risk free interest rate, ρ the risk premium specific to holding allowances as an asset in a diversified portfolio of investments, and $\mu = r + \rho$ the rate specific to risky assets in the spirit of the capital asset pricing model (CAPM).

The solution to this problem is a continuous time version of Pindyck (1993)'s model of rational commodity pricing:

$$E_t[P_{t+1}] = (1 + \mu)P_t - \psi_t \tag{1}$$

with ψ_t a convenience yield[4]. Eq. (1) therefore represents the basic relationship we want to test.

2.2 Slade & Thille (1997)

Second, assuming an allowance may be considered as an exhaustible resource[5], Slade & Thille (1997)'s model provides an analogous theoretical

[4]According to Ellerman *et al.* (2000), an agents may benefit from holding a stock of allowances on hand to buffer itself against unexpected changes in emissions, which is called a convenience yield.

[5]According to Liski & Montero (2006), the following differences may be highlighted. First, in a permits market with banking, the market may remain after the exhaustion of the bank; while the market of a non-renewable resource vanishes after the last unit extraction. Second, permits extraction and storage costs are equal to zero; while those costs are generally positive for a non-renewable resource. Third, the demand for an extra permit usually comes from a derived demand of other firms that also hold permits; while

framework by maximizing the function $V(R,p,\phi)$:

$$\begin{cases} \max_{q\tau} E_t \left\{ \int_t^\infty e^{-\rho(\tau-t)} \pi_\tau d\tau \right\} \\ \dot{R}_\tau = -q\tau \\ R_\tau \geq 0, q\tau \geq 0 \\ \frac{\partial \phi}{\phi} = \mu_\phi dt + \sigma_\phi dz_\phi \\ \\ \frac{\partial p}{p} = \mu_{pt} dt + \rho_p dz_p \end{cases}$$

with $\pi_\tau = [p_\tau q_\tau - C(q_\tau, R_\tau, \phi_\tau)]$ the risk-adjusted profit at the discount rate ρ, ϕ a random productivity shock, $\dot{R}$ the state of the bank R as a function of the extraction rate q. The last two constraints represent a set of Ito processes with drift to model uncertainty.

At the equilibrium, the evolution of the allowance price P_t is:

$$\frac{\frac{1}{\partial t} E_t \partial P_t}{P_t} = r + \beta(r^m - r) \equiv \rho \tag{2}$$

with E_t expected utility, r the risk-free interest rate, r^m the investment rate of return in a diversified portfolio, and β the risk premium specific to the asset. ρ represents to risk-adjusted discount rate used by firms to choose the emissions path that minimizes abatement costs.

Against this economic modeling background, we detail in the next section our econometric specification.

3 Econometric specification

To develop an estimable form of equation, we use the CAPM empirical specification developed by Helfand *et al.* (2006) to yield an expression for the expectation at t of the allowance price at $t+1$.

As developed in Helfand *et al.* (2006), we rearrange eq.(1) to isolate first-

the demand for an extra unit of a non-renewable resource comes more often from a derived demand of another actor (e.g., a consumer).

difference prices on the left-hand side:

$$E_t\ p_{t+1} - p_t = r_t^f p_t + \rho_t p_t - \psi_t \tag{3}$$

Rewriting $\rho_t = \dfrac{\sigma_{am}}{\sigma_{mm}}(r_t^m - r_t^f)$, which is standard practice for CAPM, yields:

$$E_t\ p_{t+1} - p_t = r_t^f p_t + \frac{\sigma_{am}}{\sigma_{mm}}(r_t^m - r_t^f)\ p_t - \psi_t \tag{4}$$

where r_t^f is the risk-free rate, r_t^m is the rate of return on the market portfolio, σ_{am} is the covariance between the rate of return of EUA prices and r_t^m, and σ_{mm} is the variance of r_t^m. The first term $r_t^f p_t$represents the Hotelling rule for cost-minimizing intertemporal arbitrage in the EU ETS market. The second term $\frac{\sigma_{am}}{\sigma_{mm}}$is the risk premium for holding allowances as part of a diversified portfolio. The expression $(r_t^m - r_t^f)$ is the excess return on the market portfolio at time t.

Since the expected value of p_{t+1} is known only with errors at time t, we substitute $E_t\ p_{t+1}$ by $p_{t+1} + \epsilon_{t+1}$:

$$p_{t+1} - p_t = r_t^f p_t + \frac{\sigma_{am}}{\sigma_{mm}}(r_t^m - r_t^f)\ p_t - \psi_t + \epsilon_{t+1} \tag{5}$$

with ϵ the error term. Note we take we take first log-differenced EUA price series. Finally, assuming the convenience yield is constant ($\psi_t = \psi$), we get:

$$p_{t+1} - p_t = \alpha + \beta_1 r_t^f p_t + \beta_2 (r_t^m - r_t^f)\ p_t + \epsilon_{t+1} \tag{6}$$

where $\alpha = -\psi$ and $\beta_2 = \frac{\sigma_{am}}{\sigma_{mm}}$. Eq. (6) represents the "base model" where $\beta_1 = 1$ tests the Hotelling rule and β_2 provides information on the CAPM risk premium for CO_2 allowances which is the difference between the expected return on allowances and the return of the risk-free asset.

3.1 Structural break

The dataset is divided into two sub-periods due to the presence of one structural break as displayed in Figure 1. Using the method developed by Lee &

Strazicich (2001)[6] that endogenously looks for structural breaks while testing for the existence of a unit root, we identify April, 20th 2006 as a breakpoint in our dataset.

For this reason, two sub-samples are considered: the sub-sample #1 goes from 01/07/2005 to 20/04/2006, and sub-sample #2 goes from 21/04/2006 to 31/05/2007. This endogenous structural break may be associated to institutional features of the EU ETS during Phase I. As 54% of the EUA spot prices adjustment was made within four days[7] starting on April 24, 2006, this break eliminates prior speculative information and revealed agents' net short/long positions. The break point may be seen as an indicator of the number of allowances either banked or borrowed at the end of the first 2005 compliance.

3.2 Base model with the environmental policy constraint

The European Commission defined the environmental constraint by validating each NAP before the launch of the emissions trading program. In 2006-2007, MS are currently operating under their NAP II for the period 2008-2012.

Without banking and borrowing provisions between the two trading periods, Ellerman & Parsons (2006) stated "*it is virtually certain that the EU ETS will then be either long or short; the likelihood of a perfect match between 1st period EUAs and emissions are extremely small. This binary outcome places a limit on 1st period prices that, when coupled with the constraint on inter-period banking, allows a probability of shortage to be calculated taking into account all the uncertainties weather, economic growth, energy prices, and the abatement response to carbon prices.*"

From this perspective, Ellerman and Parson define the probability of scarcity expected by market's participants at any point in time as the ratio between the 1st period future 2007 price and the 2nd period future price 2008,

[6] An advantage of this method is that the data themselves suggest the possible timing of structural breaks. We provide the estimated break point for the EUA prices in first difference based on model 1, with a lag of four days and 436 observations.

[7] See Buchner & Ellerman (2007).

plus 40 €, which represent the penalty[8]:

$$Pr(scarcity) = \frac{EUA_{2007}}{40\text{€} + EUA_{2008}}$$

Therefore, the higher the perceived scarcity of allowances, the higher the CO2 prices. As shown in Figure 2, the expected allowance scarcity is largely reflected in spot price changes. Introducing in the "Base model" the *epr* variable as a proxy of the environmental policy constraint during Phase I, eq.(6) becomes:

$$p_{t+1} - p_t = \alpha + \beta_1 r_t^f p_t + \beta 2(r_t^m - r_t^f)\ p_t + \beta_3 epr + \epsilon_{t+1} \tag{7}$$

3.3 Base model with the environmental policy constraint and energy market shocks

As a final step to explain 2005-2007 allowance price changes, the model is estimated with the environmental policy constraint and shocks from other energy markets related to the EU ETS. The purpose is to disentangle EUA price changes from the fluctuations of energy markets. According to Mansanet-Bataller *et al.* (2007), EUA prices are influenced by energy markets and weather.

Following Helfand *et al.* (2006), we use forecast errors[9] lagged one period for energy variables and a temperatures index as explanatory variables in eq.(7):

$$p_{t+1} - p_t = \alpha + \beta_1 r_t^f p_t + \beta_2 (r_t^m - r_t^f)\ p_t + \beta_3 epr + \beta_4 brent + \beta_5 ngas + \beta_6 temp + \epsilon_{t+1} \tag{8}$$

with *brent* the brent price series, *ngas* the natural gas price series and *temp* an European temperatures index defined below.

We detail in the next section the data used.

[8]The penalty will be 100 € thereafter and companies will also have to surrender a compensating amount of allowances.

[9]We compute forecast errors by using the method of one-step ahead forecast.

4 Data

Descriptive statistics may be found in Table 1 (see the Appendix).

4.1 CO_2 price

The price of European emissions allowances is determined in several markets: the Over-the-Counter (OTC), on spot and on futures markets.The most liquid market is the OTC market. Dealing on the OTC market transactions are usually through indutrials or brokers, consequently price data is confidential, or available through commercial energy consultancies. The London Energy Brokers Association (LEBA) produces each trading day an index price using the volume weighted average of EUA trades since December 2006. The most liquid futures market is the European Climate Exchange and the most liquid spot market is Powernext Carbon launched in June 2005. We use the daily EUA spot price (p_t in €/tonne of CO_2) negotiated from 01/07/05 to 31/05/07 on Powernext carbon.

4.2 Interest rates

The risk-free rate of return (r_t^f) is the 3-months Euribor presented as annual percentages with daily data frequency. To convert each daily observation to a daily interest rate, we used the following formula: $r = (1 + \frac{i}{4})^4 - 1$ with r the annual interest rate with a daily data frequency and i the quarterly interest rate with a daily data frequency. Thus, r_t^f is expressed in percentage points at daily rates. (See Figure 2).

The rate of return on the market portfolio of risky assets (r_t^m) is the Dow Jones EuroStoXX 50 Index annual return with a daily data frequency. To convert each daily observation to a daily interest rate, we used the following formula: $r = (1 + \frac{i}{250})^{250} - 1$ with r the annual interest rate with a daily data frequency and i the daily interest rate. Thus, r_t^m is expressed in percentage points at daily rates. (See Figure 2)

4.3 Energy prices

On energy markets, we use the brent price (brent in $/baril) is the daily brent crude Futures price negociated from 01/07/05 to 31/05/207 on the Intercontinental Exchange (ICE), the Europe's leading energy exchange, futures. The euro-dollar exchange rate provided by the European Central Bank is used to ensure all variables are transformed to the same currency. The natural gas (ngas in € /Mwh) is the daily natural gas price negociated from 01/07/05 to 31/05/207 on Zeebrugge Hub.

4.4 Weather

Concerning climate conditions, we use a temperatures index (*temp* in $°C$) as the daily data of European temperatures index published by *Tendances Carbone*[10]. It is equal to the average of national temperatures indices provided by Powernext weighted by the share of each NAP in the total of four countries. These national indices are the mean temperatures for the four countries: Spain, France, Germany and United Kingdom, calculated as the average of the temperatures at the representative regional weather station weighted by the regional population.

4.5 Stationarity tests

Because econometric results may be unreliable if the dependent variable is non-stationary, we first need to test the stationarity of allowance prices and their first-difference. One possible complication of unit root tests for stationarity is that the presence of structural changes during the time series may make rejection of a unit root more difficult (Perron (1989)). We performed usual unit root tests (ADF, PP, KPSS) for all price series and found that all of them are characterized by a unit root. When tests are applied on series in first differences, they are found to be stationary. In other words, all prices series are integrated of order 1 (I(1))[11].

[10] *Tendances Carbone* is the monthly bulletin of the European Carbon Market published by the Caisse des Depots and Powernext Carbon.

[11] Detailed results of the unit root tests are available upon request to the authors.

5 Results

Results of equations (5), (6) and (7) for each period are presented in Table 2 (see Appendix). The "Base model" is refered to as Model 1, the "Base model with the environmental policy constraint" as Model 2 and the "Base model with the environmental policy constraint and energy market shocks" as Model 3. Estimations are computed using OLS and the Newey-West procedure to correct for serial correlation and generate robust standard errors (NW-OLS). The explained variable is the first log-differenced EUA price series[12].

Based on the correlogram of the first log-differenced EUA price series, the true data generating process is characterized as an ARMA(p,q) of order 1. This is confirmed by autoregressive and moving average coefficients being statistically different from 0 in Table 2. For each regression, the Lagrange-Multiplier test indicates residuals are not autocorrelated. When the White test shows evidence of heteroskedasticity, a GARCH(p,q) model of order 1 is implemented as robustness checks in Table 3 using Bollerslev Wooldrige robust standard errors and covariance. Since both estimation techniques yield to similar results[13], we comment only NW-OLS coefficients to simplify the exposition.

5.1 Failure of the Hotelling rule for the EU ETS 2005-2007 intertemporal market

For the validation of the Hotelling rule, the null hypothesis is that $\beta_1 = 1$ in eq.(8). The confidence interval where the true value of the β parameter has a 95% probability to be is calculated according to the formula:

$$CI = [\hat{\beta} \pm 2.11 * Std.error]$$

The Hotelling rule is rejected in all models: in full period the confidence interval is $[0.0295; 0.0495]$ for Model 1 (Table 2, row 1), $[0.0182; 0.0614]$ for

[12] Thus, we are interested in the growth rate of the explained variable.

[13] GARCH coefficients are stable with significant estimates in the mean and variance equations.

Model 2 (row 2) and [0.0158; 0.0736] for Model 3 (row 3). Confidence intervals have also been computed for the two sub-periods, and yield to a similar conclusion.[14]. Hence, the EUA price path does not appear consistent with a competitive equilibrium in the 2005-2007 intertemporal market.

Yet the non-validation of the Hotelling rule for the first two years of the EU ETS is not worrying in itself. At best, it has to be seen as an indicator of scarcity under certainty, while our test was conducted under uncertainty. Helfand *et al.* (2006) tested the Hoteling rule for the time path of SO_2 permit prices and reached the similar conclusion that the SO_2 price path was not consistent with a competitive equilibrium in the intertemporal market. This question of competitive equilibrium relates directly to the issue of the market efficiency. As noted by Helfand *et al.* (2006), "*Under the first fundamental theorem of welfare economics, evidence of competitive equilibrium would imply dynamic efficiency. In this case, dynamic efficiency involves minimizing present-value cost of compliance with the intertemporal emissions regulation*". Kronenberg (2006) provides other reasons to justify this failure, for instance by paying attention to the fact that permits are characterized by a costless extraction or by focusing on strategic interactions between firms.

As noted previously, the efficiency of allowance trading is linked to the authorization of full banking and restricted borrowing (Schennach (2000), Kling & Rubin (1997)). With such provisions, market prices reflect opportunity costs leading to an efficient choice of abatement measures (Schleich *et al.* (2006)). The rejection of the competitive equilibrium assumption in the intertemporal market implies EUA price changes do not adequately reflect abatement costs at the installation level during 2005-2007. In terms of banking behaviour, after the 2005-2006 over-supplied compliance periods, most industrials have necessarily banked unused allowances before selling them on the market, whereas a minority of them may need to borrow allowances.

Another piece of information glanced from Table 2 concerns the lack of significancy of the β_2 coefficient, which means during 2005-2007 CO_2 allowances do not appear to bear a risk-premium as part of a diversified commodities portfolio.

[14] A journal of those results is available upon request to the authors.

5.2 Evidence of institutional learning within the EU ETS

As depicted in Figure 2, the perceived scarcity of allowances was increasing at the launch of the EU ETS despite early concerns of over-allocation. Our results tend to confirm this view by showing a positive influence of the environmental policy constraint on allowance price changes. During 2005-2007, we find a significant relationship between the EPR ratio and EUA price changes in Model 2 (Table 2, row 2) and Model 3 (row 3) both at 1%. While diagnostic tests indicate Model 3 performs slightly better than Model 2, it is worth underlining the stable coefficient and sign of the *epr* variable accross models. Allowance price changes are largely determined by the environmental policy constraint and react to the EPR ratio with the expected sign, *i.e.* the higher (lower) the perceived allowance scarcity the higher (lower) the allowance price.

In sub-periods, the EPR ratio is not significant before the compliance break (Table 2, rows 5 and 6), and becomes significant after the break at 5% (Model 3, row 9). Before the price adjustment, allowance trading may be characterized as hazardous or speculative, and only the release of first compliance verified emissions gave a hint about the net short/long positions at the installation level. After the break, market participants form their anticipations more accurately in a context of a low environmental policy constraint coupled to a ban on inter-period banking which explains why the EPR ratio becomes significant.

Therefore, a second main finding of our tests lies in the evidence of institutional learning within the first two years of the EU ETS. The April, 2006 structural break suggests EUA price changes are affected by institutional events such as the simultaneous releases of 2005 verified emissions by the Walloon Region of Belgium, France and Spain which serve as a proxy for the adjustment of agents' expectations. Most of the verified emissions were reported by mid-May. The fact that the EUA price responded quickly to such relevant information may be interpreted as a strong sign of efficiency of the EU ETS.

5.3 Influence of energy markets

Besides the structural break due to the first institutional compliance, another sign of the efficiency of the EU ETS is that the EUA price pattern responds to information related with energy markets. On the full period, EUA price changes respond positively to brent prices at 5% in Model 3 (Table 2, row 3)[15] and to natural gas prices at 1%. This relationship holds true in sub-periods: before the compliance break, brent and natural gas prices are positive and significant at 1% (row 6); while after the break, only the brent variable is positive and significant at 1% (row 9). These results are consistent with Mansanet-Bataller *et al.* (2007) who identified brent and natural gas prices as key energy determinants of EUA price changes.

Our point is to show the influence of the environmental policy constraint is robust to the introduction of market shocks: coefficient estimates for the EPR ratio remain significant at 1% in full period (row 3), non-significant before the break (row 6) and significant at 5% after the break (row 9).

5.4 Robustness checks

Note that adding incrementally explanatory variables to the ”Base model” also serves as robustness checks for coefficient estimates. Since financial market places are strongly correlated, the inclusion of the Euronext 100 Index instead of the DJ Euro StoXX 50 as the rate of return of a diversified portfolio does not change the results and the Hotelling rule is still rejected in all models. As an additional robustness check, we conduct a Chow breakpoint test for the determination of the structural break and reject the null hypothesis that the sample does not contain a structural break at a 5% confidence level[16].

[15] While the negative sign of the brent variable lagged five days is due to price adjustments, we verify in the following regressions that brent prices indeed impact positively EUA price changes.

[16] A journal of those results may be obtained upon request to the authors

6 Conclusion

This article may be seen as an attempt to characterize the efficiency of the intertemporal market during Phase I of the EU ETS. Due to the ban on inter-period banking between 2007 and 2008, we have highlighted a total disconnection between prices of first and second period allowances with a clear decline of the first period prices. Within the first 2005-2007 period, market participants are expected to use free banking and borrowing of allowances. In this context, we test whether the EUA spot prices follow the Hotelling rule as the key element of a competitive equilibrium and find evidence for the rejection of the rule.

A second main finding of our test lies in the evidence of an institutionnal learning within the two first years of the EU ETS. We show statistical evidence of an endogenous structural break stated in 20 April,2006, which serves as a proxy for the adjustment of agents' expectations and reveals EUA price changes are affected by institutional events. Our results also stress a significant relationship between EUA price changes and the environmental constraint proxied by the perceived allowance scarcity. Before the first compliance in April 2006, EUA prices path were influenced by the environmental constraint with a lag of five days whereas after the endogenous structural break EUA prices responded to it without lags. Market participants were basically learning how to use tradable permits. These results tend to counterbalance the previous analysis and provides some signs of efficiency of the EU ETS during Phase I.

We also find evidence that EUA prices are influenced by other market shocks. We incorporated energy and temperatures variables to isolate effects of the current economic situation on EUA prices, and validated brent prices, natural gas prices and the European temperatures index as influencing EUA price variations. The specific effects of energy markets and climatic conditions on the European carbon market needs to be further assessed.

7 Appendix

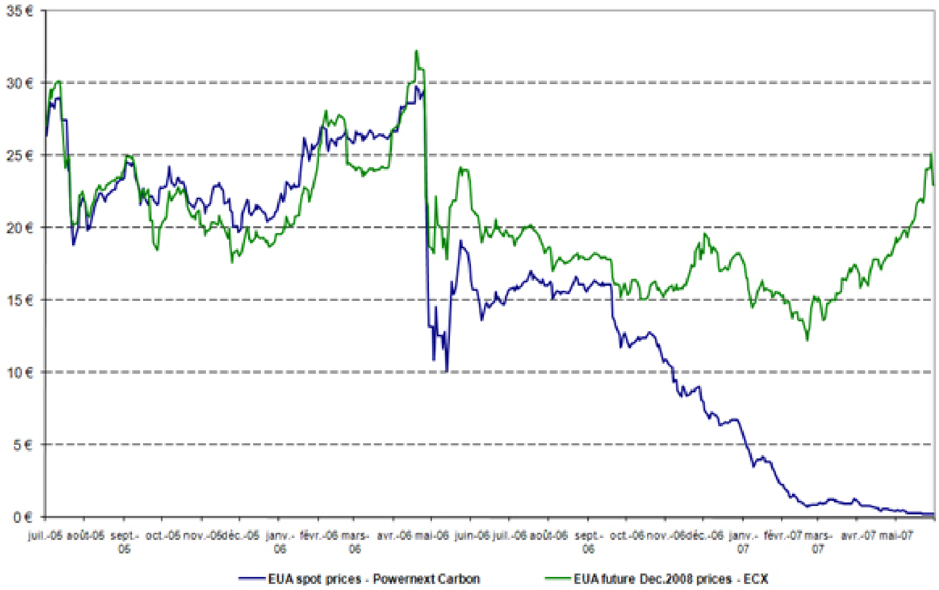

Figure 1: EUA Prices and Volume Exchanged from 01/07/05 to 31/05/07
Source: Powernext carbon

Figure 2: The probability of EUA allowances shortage at the end of the 1st period *Source*: Ellerman & Parsons (2006)

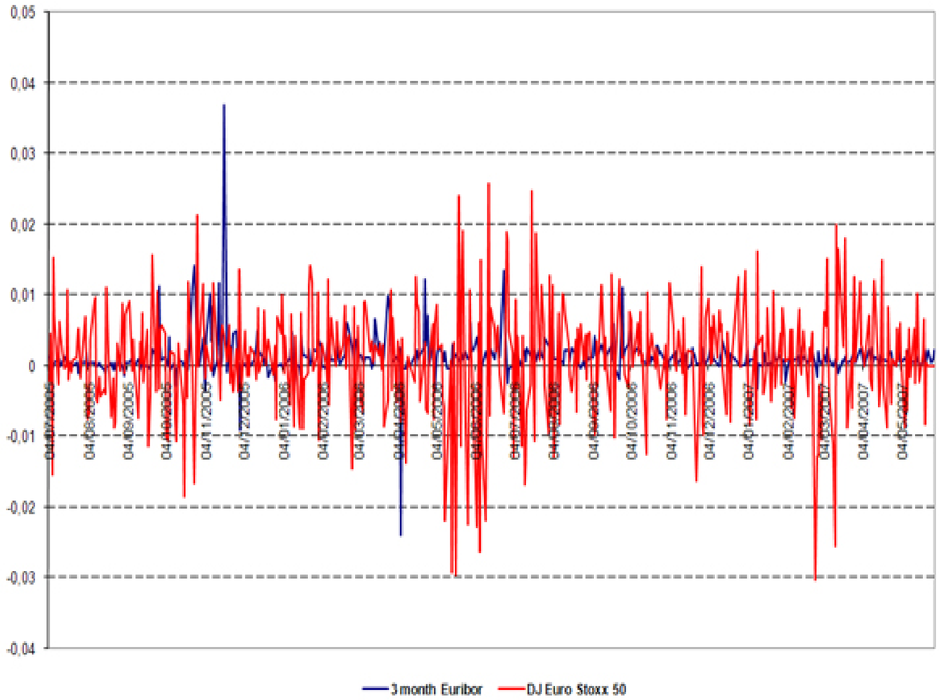

Figure 3: Rates of return for 3 Months-Euribor and Dow Jones Euro StoXX 50 in percentage points at daily rates *Source:* Banque de France and Euronext

Notes on Tables:

Table 1 shows descriptive statistics for the energy price series under consideration. Table 2 presents the results of equations (5), (6) and (7) regressing by NW-OLS. The dependent variable is the first log-differenced EUA price series. *** indicates significance at 1% level, ** at 5% level and * at 10% level. In Table 3, GARCH estimation are computed for the "full period" and the "after the compliance break period" when the White test indicated the presence of heteroskedasticity. The following diagnostic tests for the quality of the regressions are reported in each table: the simple R-squared, the adjusted R-squared, the p-value of the F-test statistic ($F-Stat$), the Durbin-Watson statistic ($D.W.$), the p-value of the the Breusch-Godfrey Serial Correlation Lagrange Multiplier test (LM), the p-value of the White heteroskedasticity test ($White\ test$), the Akaike Information Criterion (AIC) and the Schwartz Criterion (SC).

	Mean	Median	Max.	Min.	Std. Dev.	Skew.	Kurt.	Obs.
Full period								
p_t	15.221	16.090	29.750	0.250	9.070	-0.353	1.834	492
brent	0.002	0.016	57.919	-58.168	5.287	0.031	116.522	492
ngas	-0.016	-0.155	11.566	-10.550	1.654	0.976	14.868	492
Before the compliance break								
p_t	23.819	22.950	29.750	18.850	2.564	0.435	2.104	206
brent	0.002	0.014	57.919	-58.168	5.804	-0.074	98.057	206
ngas	-0.005	-0.304	11.566	-10.550	1.947	1.024	14.056	206
After the compliance break								
p_t	9.029	9.520	29.430	0.250	6.715	0.118	2.017	286
brent	-0.013	0.033	57.776	-57.283	4.891	0.154	134.780	286
ngas	0.001	-0.015	7.206	-6.844	1.410	0.783	11.927	286

Table 1: Descriptive Statistics

	Full period			*After the compliance break*		
Variable	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**
	(1)	(2)	(3)	(4)	(5)	(6)
$p_t(-1)$	-0.3117*	-0.3479**	-0.3368**	-0.1974	-0.2435	-0.1794
	(0.1772)	(0.1657)	(0.1660)	(0.1941)	(0.1903)	(0.1572)
ma(1)	0.5938***	0.6130***	0.6042***	0.4954***	0.5282***	0.4904***
	(0.1432)	(0.1367)	(0.1373)	(0.1763)	(0.1719)	(0.1504)
Constant	-0.0109***	-0.0358***	-0.0356***	-0.0238***	-0.0351***	-0.0363***
	(0.0041)	(0.0098)	(0.0098)	(0.0064)	(0.0117)	(0.0109)
$r_t^f\ p_t$	-0.0099	-0.0216	-0.0281	0.3078**	0.1467	0.2310*
	(0.0187)	(0.0189)	(0.0198)	(0.1376)	(0.1321)	(0.1249)
$(r_t^m - r_t^f)\ p_t$	-0.0099	-0.0097	-0.0098	-0.0155	-0.0202	-0.0121
	(0.0089)	(0.0086)	(0.0086)	(0.0257)	(0.0228)	(0.0247)
epr		0.0974***	0.0974***			0.1021**
		(0.0291)	(0.0289)			(0.0477)
epr(-1)					0.0887*	
					(0.0522)	
brent						0.0159***
						(0.0040)
ngas			0.0016***			
			(0.0006)			
temp						
R-squ.	0.1232	0.1449	0.1481	0.1247	0.1322	0.1932
Adj. R-squ.	0.1122	0.1323	0.1336	0.1013	0.1051	0.1643
F-Stat	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
D.W.	1,9750	1.9799	1.9854	1,9861	1.9702	1.9797
LM test	0.5398	0.6435	0.7125	0.2327	0.0701	0.1885
White test	0.0000	0.0000	0.0000	0.0277	0.0001	0.0001
AIC	-2.9026	-2.9236	-2.9232	-2.6940	-2.6941	-2.7583
SC	-2.8421	-2.8543	-2.8453	-2.5901	-2.5753	-2.6246

Table 2 : Hotelling-CAPM Model Tests

	Full period			*After the compliance break*		
Variable	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**
	(7)	(8)	(9)	(10)	(11)	(12)
$p_t(-1)$	-0.6980***	-0.6927***	-0.6932***	-0.5851***	-0.6465***	-0.4156***
	(0.0955)	(0.0899)	(0.0866)	(0.1185)	(0.1236)	(0.0708)
ma(1)	0.8159***	0.8095***	0.8135***	0.7849***	0.8118***	0.6910***
	(0.0749)	(0.0682)	(0.0656)	(0.0895)	(0.0985)	(0.0664)
Constant	0.0036	-0.0053	-0.0066	-0.0071	-0.0451***	-0.0482***
	(0.0025)	(0.0048)	(0.0052)	(0.0045)	(0.0143)	(0.0123)
$r_t^f\ p_t$	-0.0135	-0.0132	-0.0141	0.0064	-0.0241	-0.0011
	(0.0131)	(0.0134)	(0.0127)	(0.0636)	(0.0579)	(0.0571)
$(r_t^m - r_t^f)\ p_t$	-0.0049	-0.0053	-0.0060	-0.0314***	-0.0053	-0.0108***
	(0.0045)	(0.0046)	(0.0045)	(0.0105)	(0.0046)	(0.0001)
epr		0.0245*	0.0275**			0.1759***
		(0.0145)	(0.0153)			(0.0441)
epr(-1)					0.1527***	
					(0.0536)	
brent						0.0062***
						(0.0021)
ngas			0.0005			
			(0.0004)			
temp						
ARCH(1)	0.5039***	0.5399***	0.5287***	-0.0229***	-0.0246***	-0.0287***
	(0.0462)	(0.0528)	(0.0502)	(0.0009)	(0.0002)	(0.0009)
GARCH(1)	0.6099***	0.5903***	0.5993***	1.0395***	1.0402***	1.0434***
	(0.0300)	(0.0313)	(0.0306)	(0.0004)	(0.0004)	(0.0014)
R-squ.	0.0303	0.0435	0.0506	0.0538	0.0860	0.1499
Adj. R-squ.	0.0119	0.0232	0.0284	0.0155	0.0447	0.1074
F-Stat	0.0992	0.0199	0.0102	0.1878	0.0270	0.0001
D.W.	1.6894	1.7230	1.7281	1.8142	1.8277	1.9658
AIC	-3.6243	-3.6222	-3.6239	-3.2017	-3.2336	-3.2918
SC	-3.5377	-3.5269	-3.5200	-3.0531	-3.0702	-3.1135

Table 3 : Robustness GARCH estimation

References

Buchner, B., & Ellerman, E.D. 2007. *The European Union Emissions Trading Scheme: Origins, Allocation, and Early Results*. Review of Environmental Economics and Policy.

Ellerman, A.D., & Parsons, J. 2006. *Shortage, Inter-period Pricing, and Banking*. Tendances Carbone, Volume 5.

Ellerman, A.D., Joskow, P.L., Schmalensee, R., Montero, J.P., & Bailey, E. 2000. *Markets for Clean Air: The US Acid Rain Program*. 2nd edn. Cambridge University Press.

Helfand, G.E., Moore, M.R., & Liu, Y. 2006. *Testing for dynamic efficiency of the Sulfur Dioxide Allowance Market*. Working Paper, University of Michigan.

Kling, C., & Rubin, J. 1997. Bankable Permits for the Control of Environmental Pollution. *Journal of Public Economics*, **64**, 101–115.

Kronenberg, T. 2006. *Should we worry about the failure of the Hotelling rule?* Working Paper, Maastricht University.

Lee, J., & Strazicich, M.C. 2001. Testing the Null of Stationarity in the Presence of a Structural Break. *Applied Economics Letters*, **8**, 377–382.

Liski, M., & Montero, J.P. 2006. On Pollution Permit Banking and Market Power. *Journal of Regulatory Economics*, **29**(3), 283–302.

Mansanet-Bataller, M., Pardo, A., & Valor, E. 2007. CO_2 Prices, Energy and Weather. *The Energy Journal*, **28**(3), 67–86.

Perron, P. 1989. The Great Crash, the Oil Price Shock, and the Unit Root Hypothesis. *Econometrica*, **57**(6), 1361–1401.

Pindyck, R.S. 1993. the Present Value Model of Rational Commodity Pricing. *the Economic Journal*, **103**, 511–530.

Rubin, J. 1996. A model of Intertemporal Emission Trading, Banking, and Borrowing. *Journal of Environmental Economics and Management*, **31**, 269–286.

Schennach, S.M. 2000. The Economics of Pollution Permit Banking in the Context of Title IV of the 1990 Clean Air Act Amendments. *Journal of Environmental Economics and Management*, **40**, 189–210.

Schleich, J., Ehrhart, K.M., Hoppe, C., & Seifert, S. 2006. Banning Banking in EU Emissions Trading? *Energy Policy*, 112–120.

Slade, M.E., & Thille, E. 1997. Hotelling Confronts CAPM: A Test of the Theory of Exhaustible Resources. *The Canadian Journal of Economics*, **30**(3), 685–708.