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European Carbon Prices and Banking Restrictions : Evidence from Phase I (2005-2007)

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Abstract

The price of European Union Allowances (EUAs) has been declining at far lower levels than expected during Phase I (2005-2007). Previous literature identifies among its main explanations over-allocation concerns, early abatement efforts in 2005 and possibly decreasing abatement costs in 2006. We advocate low allowance prices may also be explained by banking restrictions between 2007 and 2008 which undermine the ability of the EU ETS to provide an efficient price signal. Based on a Hotelling-type analysis, our results suggest EUA prices do not reflect adequately abatement costs. We also give evidence that the French ban on banking and the expected allowance scarcity at the end of Phase I computed by the Ellerman-Parsons ratio contribute to the explanation of low EUA prices. This situation may be interpreted as a sacrifice of the temporal flexibility offered to industrials in Phase I to give a chance to correct design inefficiencies and achieve an efficient price pattern leading to effective abatement efforts in Phase II.

JEL Codes: Q28, Q52, Q58

Keywords: Carbon emissions trading, EU ETS, Banking, Borrowing, Hotelling rule, Ellerman-Parsons ratio.

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1 Introduction

On the European Union Emissions Trading Scheme (EU ETS) launched in 2005 to help Member States (MS) achieve their Kyoto target to reduce 1990 emissions by 8% during 2008-2012, covered installations are only allowed for banking and borrowing allowances within 2005-2007 and within 2008-2012. Each year, when abatement together with endowment of 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. A fundamental statement on emissions trading is that allowance trading is efficient over time only if banking and borrowing are authorized (Rubin (1996), Schennach (2000)). With such provisions, market prices reflect opportunity costs leading to an efficient choice of abatement measures (Schleich *et al.* (2006)). The most prominent example of the key role of such provisions is the US Acid Rain Program where banking has been a major feature in the success[1] of this emissions trading scheme (Ellerman *et al.* (2000), Ellerman & Montero (2007)).

None empirical analysis on the impact of the intra-period banking coupled with a ban on inter-period banking on EUA prices has yet been realised. In a game simulation, Ehrhart *et al.* (2005) found that a ban on banking leads to an inefficient adjustment with first an under-investment in abatement technologies and a low allowance price during 2005-2007; and second a more stringent cap with a price peak and over investment in emission reduction during 2008-2009.

Among the main explanations of low allowance prices towards the end of Phase I, the 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 com-

[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.

pared to coal (Buchner & Ellerman (2007), Mansanet-Bataller *et al.* (2007)). Therefore, a thorough analysis of banking and borrowing provisions is missing and it appears necessary to disentangle those effects on allowance prices which 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 expected. 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.

Within 2005-2007, participants are expected to use unrestricted banking and borrowing. Based on this assumption, we test in an empirical approach whether the allowance price pattern is consistent with a competitive equilibrium in the intertemporal market when banking and borrowing provisions are allowed. Schennach (2000)'s theoretical model of the intertemporal allowance market applied by Helfand *et al.* (2006) to the US SO_2 market guides our Hotelling-type analysis. The impact of the late restriction on inter-period banking is evaluated through dummy variables representing official communications between France, Poland and the European Commission (EC). The probability of allowance shortage at the end of Phase I computed by Ellerman & Parsons (2006) ratio (EPR)[3] is used to characterize how the allowance price reacts to the environmental policy constraint during Phase I.

Compared to the literature on efficient banking in the US SO_2 Program, our results show the inter-period banking restriction undermines the ability of the EU ETS to provide an efficient price signal. Phase I allowances do not appear to reflect adequately abatement costs. Following the disclosure

[2]With complete information and emission targets being known, Hotelling (1931) shows the percentage change in net-price per unit of time of an exhaustible resource should be equal to the discount rate 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)). 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.

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

of 2005 verified emissions on April, 2006 we provide a sharper explanation of low EUA prices with both the EPR ratio and French official communications related to the ban on banking being significant. These results are robust to the introduction of energy market shocks and weather conditions previously identified as being the main determinants of EUA prices.

The paper is organized as follows. Section 2 provides an assessment of the banking and borrowing provisions in the EU ETS. Section 3 tests the effects of banking restrictions on allowance prices and presents the results.

2 Background

This section reviews the environmental and economic effects of banking and borrowing, the motives that led Member States to ban banking and borrowing between 2007 and 2008, and the allowance price development along with its charateristic structural break on April, 2006.

2.1 Environmental and economic effects of banking

In terms of environmental effects, allowance banking and borrowing may change the temporal path of emissions and aggregate emissions. While banking *reduces* social damages in presence of a convex damage function coming from emissions and stricter future standards (Kling & Rubin (1997)), unrestricted borrowing may have *negative* consequences with a concentration of emissions on early periods by delaying abatement decisions[4]. To correct these unwanted allowance paths, the regulator may introduce a non unitary Intertemporal Trading Ratio (ITR)[5] including interests on banking and dis-

[4]There may also be a risk of building a bank of borrowed allowances too large by the end of the period. This hypothesis, suggested by Grubb & Neuhoff (2006), would imply an additional constraint during the negotiation phase of the post-2012 period of the EU ETS if the amount of borrowed allowances accumulated by industrials, and that could legally be transferred to the next period, appears unsustainably large.

[5]Kling & Rubin (1997) suggest the implementation of a discount rate equal to the industry average rate of interest used to finance medium term capital expenditures. For greenhouse gases, the optimal rate of intertemporal substitution has been suggested by Leiby & Rubin (2001) as being "*the ratio of current marginal stock damages to the discounted future value of marginal stock damages less the decay rate of emissions in the*

couraging borrowing : if firms borrow a lot of allowances in early periods, they will reimburse more allowances than actually used in the next period. Furthermore, banking provisions could affect the rate of non-compliance and the resulting excess emissions[6].

In terms of economic effects, the theoretical literature suggests allowance banking and borrowing may improve economic efficiency under specific assumptions[7]. First, banking links future allowance prices to the spot price as stated by Maeda (2004). Second, banking and borrowing improve price stability (Ellerman & Montero (2002)). If inter-period banking is not allowed, allowance prices are likely to be unstable at the end of each compliance period. In case of surplus, allowances are worthless and their price should fall to zero. In case of excess emissions, the allowance price should rise sharply at the end of the period. Third, banking and borrowing improve liquidity in the allowance market by increasing the quantity of allowances available to the market[8] and the volume of allowances traded (Godby *et al.* (2000)).

Following this review of the various effects of banking and borrowing that need to be accounted for when tailoring environmental regulation, we expose in the next section the motivation of MS leading to the inter-period ban on banking.

2.2 Reasons to ban banking between 2007 and 2008

MS decided to prohibit the transfer of unused allowances from the EU ETS Phase I (2005-2007) into the Kyoto Protocol (KP) first commitment period (2008-2012). Therefore, installations covered by the EU ETS may not use

atmosphere", increased by the difference between the discount rates of firms and the social planner.

[6]Cason & Gangadharan (2004) find that banking increases non-compliance and total emissions in experiments with weak enforcement. Borrowing provisions could increase the rate of compliance in current period, but that would only shift excess emissions to the next period.

[7]*i.e.* the abatement cost function does not change over time and there is complete information on the marginal damage function and emissions of sources (Rubin (1996), Schennach (2000)).

[8]This positive effect of banking may be distorted, for instance by initial allocation, leading to the *Hot Air* situation in the Kyoto Protocol.

banked allowances during Phase I to meet their obligations during Phase II (2008-2012) except through advance agreements for purchase of Certified Emissions Reductions (CERs)[9]. Neither may installations use borrowed allowances between the two periods[10].

Discussions on the banking feature were characterized by sudden changes. At the beginning of the EU ETS in 2005, all MS decided, with the exception of Poland and France, against the inter-period transfer of allowances: all allowances not surrendered by the end of 2007 will be cancelled and not transferred to the subsequent five-years implementation period. Since then, Poland and France decided to ban the transfer of allowances to Phase II.

Two main reasons may explain this inter-period ban on banking by MS *vis-à-vis* their Kyoto commitment (Ehrhart *et al.* (2005), Schleich *et al.* (2006)). First, the transfer of banked allowances from 2007 to 2008 may weaken the ability of a MS to meet its Burden-Sharing Agreement target starting in 2008 and second, large quantities of banked allowances may trigger the Commitment Period Reserve (CPR) rule which postulates to keep a reserve of Assigned Amount Units (AAUs)[11] above 90%. Second, the inter-period ban on banking avoids negative side effects at the EU ETS level. It might have been problematic for MS to forecast in 2006 the amount of banked allowances when drawing up their National Allocation Plans (NAPs) for 2008-2012. In presence of unexpected large amounts of banked allowances, sectors non-covered by the EU ETS need to make additional abatement efforts [12].

[9] *i.e.* allowances from Clean Development Mechanism (CDM) projects.

[10] In practice, the link between the European and international transactions registries, respectively the Community Transaction Log and the International Transaction Log will be effective before the end of 2007. This communication will allow deliveries of credits from CDM projects on European registries.

[11] *i.e.* allowances from the KP.

[12] The relationship between sectors covered / not covered by the EU ETS adds another layer of complexity to the scheme, given that mandatory national abatement targets were signed at the national level under the Kyoto Protocol.

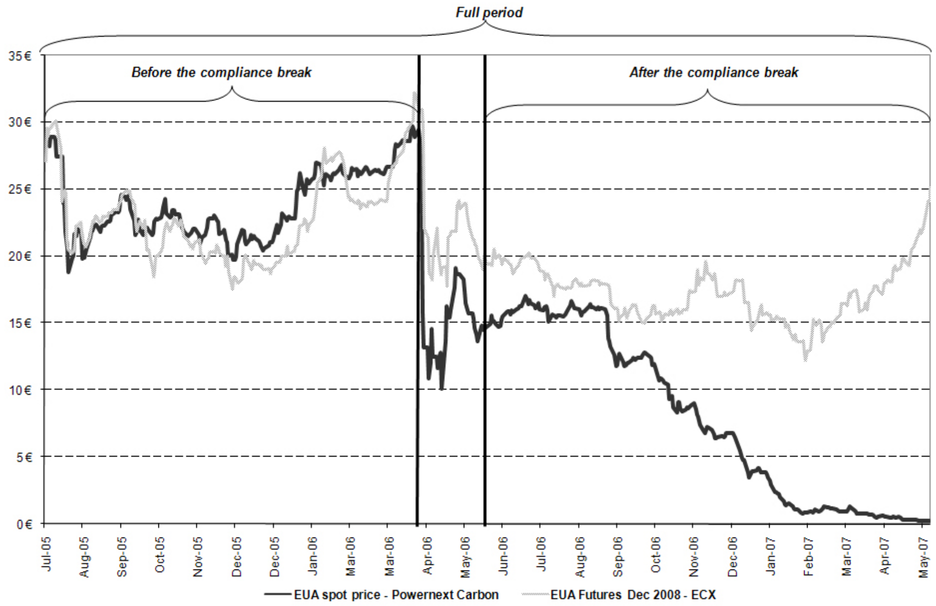

Figure 1: EUA Spot anf Futures Prices from 2005/07/01 to 2007/05/31
Source: Powernext Carbon and ECX

2.3 Price development

European Union Allowances (EUAs) price series for Phase I and II follow different patterns. Beginning at 8 € on January 1, 2005 EUA prices rose to 25-30 € until the release of 2005 verified emissions on April 24, 2006 which had a depressive effect on EUA prices as shown by the sharp break in the EUA spot price and EUA futures December 2008 price in Figure 1. Verified emissions were about 80 million tons or 4% lower than the amount of allowances distributed to installations for 2005 emissions (Buchner & Ellerman (2007)). The EU ETS is sending two price signals responding to different dynamics. As the 2006 compliance confirmed the allowance market is long[13], Phase I allowance prices have been declining towards zero, whereas Phase II allowance prices have been increasing to levels up to 20 € primarily due to institutional factors disclosed by the EC which has reaffirmed its will to enforce tighter targets in Phase II.

[13] 1.45% according to the EU Press Release IP/06/612 on May 15, 2006 available at http://europa.eu.

As displayed in Figure 1, the dataset is divided into two sub-periods due to the presence of one structural break following 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. Using the method developed by Lee & Strazicich (2001) and Lee & Strazicich (2003)[14] that endogenously looks for structural breaks while testing for the existence of a unit root, we identify April 20, 2006 as a breakpoint in our dataset and exclude extreme price changes from our regressions. Two sub-periods need to be considered : the "before the compliance break" period from 2005/07/01 to 2006/04/20 and the "after the compliance break" period from 2006/06/22 to 2007/05/31. This endogenous structural break may be associated to institutional features of the EU ETS during Phase I. As 54% of the EUA spot price adjustment was made within four days[15] starting on April 24, 2006 this break eliminates prior uncertain information and reveals agents' net short/long positions.

As expressed before, the main explanations of low EUA prices toward zero the end of Phase I include over-allocation concerns, the possibility early abatement and the influence of climatic and energy variables (Buchner & Ellerman (2007), Mansanet-Bataller *et al.* (2007)) The model estimated in the next section evaluates the specific role played by banking and borrowing provisions that may contribute to a sharper explanation of low allowance price levels.

3 Analysis

In this section, we describe first the theoretical framework from which we derive our estimation strategy. Second, we explicit our econometric specification. Third, we present the data sources. Fourth, we interpret the results.

[14]In this method, data themselves suggest the possible timing of structural breaks. Their GAUSS code may be found at *http://www.cba.ua.edu/ jlee/gauss/ls.txt*.

[15]See Buchner & Ellerman (2007).

3.1 Rationale behind a Hotelling-type analysis

The model we estimate is based on two strands of literature developped by Schennach (2000) and Slade & Thille (1997) which were first applied to the US SO_2 market by Helfand *et al.* (2006).

First, Schennach (2000) studies the banking behavior of regulated industrials in the US 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 price path would increase smoothly at the rate of interest according to the Hotelling rule. Under uncertainty, the model features risk-neutral agents minimizing their abatement costs under a banking constraint and with a discount 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 E_t the expectation value given the information available at time t, p_{t+1} the commodity price at time $t + 1$, r the risk free interest rate, ρ the risk premium specific to holding allowances as an asset in a diversified portfolio of investments, $\mu = r + \rho$, and ψ_t a convenience yield[16]. Eq. (1) therefore represents the basic relationship we want to test.

Second, assuming an allowance may be considered as an exhaustible resource[17], Slade & Thille (1997) provide an analogous theoretical framework by maximizing the expected present value of a risk adjusted profit with re-

[16]According to Ellerman *et al.* (2000), 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.

[17]According to Liski & Montero (2006), the following differences may be highlighted. First, on 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 extracted. 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 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).

spect to the state of the resource bank[18] and a random productivity shock. At the equilibrium, the evolution of the allowance price p_t follows a Hotelling-CAPM relationship between the risk-free interest rate, the investment rate of return in a diversified portfolio and the risk premium specific to the asset similar to eq. (1).

As developed in Helfand *et al.* (2006), we rearrange eq. (1) to isolate first-difference prices on the left-hand side:

$$E_t\ p_{t+1} - p_t = r_t^f p_t + \rho_t p_t - \psi_t \tag{2}$$

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

$$E_t\ p_{t+1} - p_t = r_t^f p_t + \frac{\sigma_{am}}{\sigma_{mm}}(r_t^m - r_t^f)\ p_t - \psi_t \tag{3}$$

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. 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 $p_{t+1} + \epsilon_{t+1}$:

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

where the dependent variable is the first log-differenced EUA price series and ϵ the error term. Next, assuming the convenience yield is constant ($\psi_t = \psi$) and adding dummy variables to get rid of extreme price changes, we get:

$$p_{t+1} - p_t = \alpha + \beta_1 r_t^f p_t + \beta_2 (r_t^m - r_t^f)\ p_t + \beta_3 p_t min + \beta_4 p_t max + \epsilon_{t+1} \tag{5}$$

where $\alpha = -\psi$, $\beta_2 = \frac{\sigma_{am}}{\sigma_{mm}}$, $p_t min$ and $p_t max$ the dummy variables for min-

[18] As a linear function of the extraction rate.

imum and maximum price changes. In eq. (5), the null hypothesis $\beta_1 = 1$ 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.

3.2 Environmental policy constraint

The EC defined the environmental policy constraint by validating each NAP before the launch of the EU ETS on January 1, 2005 even if some NAPs were validated after the beginning of the scheme. During 2006-2007, MS are currently negociating their NAP for Phase II.

As noted previously, France and Poland initially decided to authorize industrials to transfer allowances to Phase II. Governments changed this option during NAPs II negotiations until the EC final decision on March 26, 2007 that validated the ban on banking. To capture these effects, we introduce two dummy variables, $banfr$ for France and *banpl* for Poland, that correspond to official communications between MS and the EC leading to the restriction on banking as summarized in Table 1.

Without banking and borrowing provisions between Phase I and II, 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 first period EUAs and emissions are extremely small. This binary outcome places a limit on first 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*". In this perspective, the probability of scarcity expected by market participants at any point in time is defined as the ratio between Phase I future price series of delivery December, 2007 and Phase II future price series of delivery December, 2008 plus 40 € which represents the penalty[19]:

[19]The penalty will be 100 € during Phase II and industrials also need to surrender a compensating amount of allowances.

Table 1: Official communications between France, Poland and the European Commission regarding NAPs II
Source: European Commission Environment DG

Steps	Action	France	Poland
NAP II submission	*Letter dated*	2006/09/28	2006/06/30
	EC registration	2006/09/28	2006/07/06
Additional information	*Letter dated*	2006/10/27	2006/12/29
		2006/12/29	2007/01/09
		2007/01/17	
		2007/03/14	
		2007/03/15	
	EC registration	2006/11/08	2007/01/08
		2007/01/05	2007/01/23
		2007/01/23	
	Withdrawing	2006/11/28	
EC decision		2007/03/26	2007/03/26

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

Therefore, the higher the expected allowance scarcity, the higher EUA prices. As shown in Figure 2, the expected allowance scarcity is largely reflected in allowance price changes.

Introducing the $banfr$, $banpl$ and epr variables relative to the environmental policy constraint, eq. (5) becomes:

$$\begin{aligned} p_{t+1} - p_t =& \alpha + \beta_1 r_t^f p_t + \beta_2 (r_t^m - r_t^f)\, p_t + \beta_3 p_t min + \beta_4 p_t max \\ & + \beta_5 epr + \beta_4 banfr + \beta_6 banpl + \epsilon_{t+1} \end{aligned} \tag{6}$$

with epr the probability of EUA allowance shortage at the end of Phase I, $banfr$ and $banpl$ the dummy variables related to the ban of banking by France and Poland. Eq. (6) constitues the general form of the model we estimate on the full period and corresponding two sub-periods.

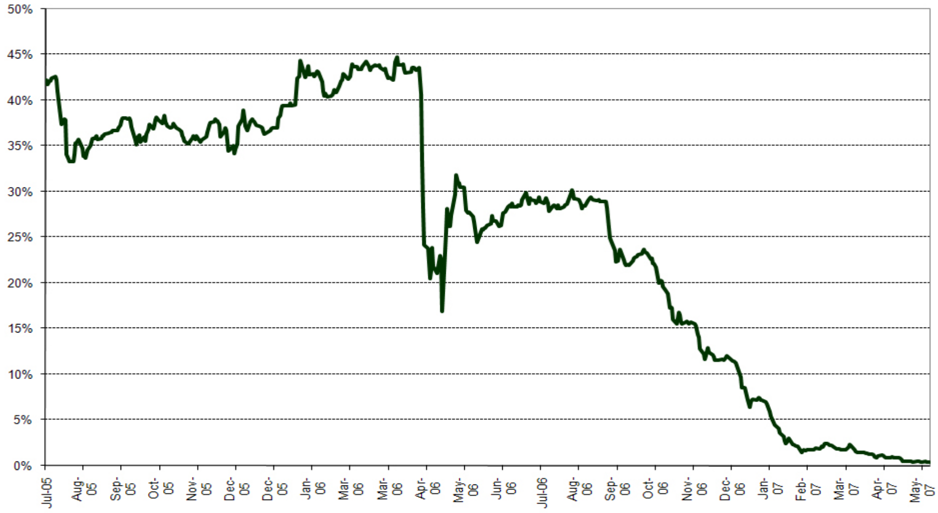

Figure 2: Probability of EUA shortage *à la* Ellerman & Parsons (2006)
Source: ECX

3.3 Energy market shocks

To avoid model misspecification, we introduce Brent prices, Natural gas prices and weather conditions that were identified as being the main determinants of EUA prices by Mansanet-Bataller *et al.* (2007). This final step also serves as robustness check of the results obtained in eq. (6) which becomes:

$$\begin{aligned} p_{t+1} - p_t = & \alpha + \beta_1 r_t^f p_t + \beta_2 (r_t^m - r_t^f)\ p_t + \beta_3 p_t min + \beta_4 p_t max \\ & + \beta_5 epr + \beta_6 banfr + \beta_7 banpl \\ & + \beta_8 brent + \beta_9 ngas + \beta_{10} temp + \epsilon_{t+1} \end{aligned} \tag{7}$$

with *brent* the Brent price series, *ngas* the Natural gas price series[20] and *temp* an European temperature index defined below.

[20] Following Helfand *et al.* (2006), we compute forecast errors using the "one-step ahead" forecast method for energy variables.

4 Data

4.1 The carbon price

The EUA price is determined on several markets: the over-the-counter (OTC), spot and futures markets. The most liquid market is the OTC market, where transactions are usually operated through industrials or brokers and consequently price data is confidential, or available through commercial energy consultancies[21]. The most liquid futures market is the European Climate Exchange (ECX) and the most liquid spot market is Powernext Carbon launched on June, 2005. We use the daily EUA spot price (p_t in € per ton of CO_2) negotiated on Powernext carbon. The data range goes from 2005/07/01 to 2007/05/31, i.e. from the start of the Powernext Carbon trading platform until the period where Phase I allowance prices gear toward zero.

4.2 CAPM rates of return

The risk-free rate of return (r_t^f) is the 3-months Euribor presented as annual percentages with daily data frequency. The rate of return on the market portfolio of risky assets (r_t^m) is the Dow Jones EURO STOXX 50 Index annual return with a daily data frequency. We convert each daily observation to a daily interest rate. Thus, r_t^f and r_t^m are expressed in percentage points at daily rates (see Figure 3 in the Appendix).

4.3 Energy prices

On energy markets, the Brent price (*brent* in US $ per baril) is the daily brent crude futures price negotiated on the Intercontinental Exchange (ICE), the European leader on futures energy exchange. The Natural gas price (*ngas* in € per Mwh) is the daily natural gas price negotiated on Zeebrugge Hub. The euro-dollar exchange rate provided by the European Central Bank is used

[21] For instance, the London Energy Brokers Association (LEBA) produces each trading day an index price using the volume weighted average of EUA trades since December 2006.

to ensure all variables are transformed to the same currency. Descriptive statistics for energy variables are presented in Table 5 (see the Appendix).

4.4 Temperatures

Concerning climate conditions, the daily data of the European temperature index published by Tendances Carbone[22] is used. It is equal to the average of national temperature Powernext weather indices (in $°C$) weighted by the share of each NAP in the total of four countries. These national indices are the mean temperature for 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 all price series 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) and found that all price series 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))[23].

5 Results and discussion

Results of equations (6) and (7) for the full period and the two sub-periods are presented in Table 2, 3 and 4. Estimations are computed using OLS and the Newey-West procedure to correct for serial correlation and generate

[22]Tendances Carbone is the monthly bulletin of the European Carbon Market published by the Caisse des Dépôts and Powernext Carbon.

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

robust standard errors (NW-OLS). The dependent variable in this analysis is the first log-differenced EUA price series[24]. Based on its correlogram, 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. The quality of the regressions is verified through the following diagnostic tests: 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). For each regression, the Lagrange-Multiplier test indicates residuals are not autocorrelated. Robustness checks concerning the choice of the rate of return on the market portfolio of risky assets, the determination of the structural break and the presence of heteroskedasticity in coefficient estimates are detailed in the Appendix.

5.1 Full sample

Regression results for the full sample are given in Table 2. The significance of $r_t^f p_t$ in row (1) is not a primary concern, since it tests the restriction $\beta_1 = 0$. For the validation of the Hotelling rule, we are rather interested in the null hypothesis $\beta_1 = 1$. Thus, we calculate the confidence interval where the true value of the β parameter has a 95% probability to be according to the formula: $CI = [\hat{\beta} \pm 2.11 * Std.error]$. These calculations[25] lead us to reject the Hotelling rule in full period. The interpretation is that with the inter-period banking restriction the EU ETS does not achieve a competitive equilibrium that would minimize compliance costs through the use of temporal flexibility mechanisms. Several other inferences may be made from the Hotelling-CAPM model. The lack of significancy of the β_2 coefficient suggests CO_2 allowances do not bear a risk-premium as part of a diversified commodities portfolio. Both *ptmin* and *ptmax* dummy variables are signifi-

[24] Thus, we are interested in the growth rate of the dependent variable.

[25] Not shown but available from the authors by request.

Table 2: Hotelling-CAPM Model: Full sample results

	(1)	(2)
$p_t(-1)$	-0.5131***	-0.5145***
	(0.1239)	(0.1239)
ma(1)	0.8191***	0.8189***
	(0.0830)	(0.0830)
Constant	-0.0345***	-0.0344***
	(0.0115)	(0.0115)
$r_t^f\ p_t$	-0.0026	-0.0031
	(0.0149)	(0.0140)
$(r_t^m - r_t^f)\ p_t$	-0.0001	-0.0009
	(0.0090)	(0.0089)
$\mathrm{p}_t$min	-0.1281***	-0.1262***
	(0.0218)	(0.0211)
$\mathrm{p}_t$max	0.0387**	0.0386**
	(0.0199)	(0.01995)
epr	0.0908***	0.0904***
	(0.0315)	(0.0316)
banfr	0.0219**	0.0216**
	(0.0106)	(0.0107)
ngas		0.0016**
		(0.0009)
ngas(-1)		0.0016**
		(0.0008)
brent		
banpl		
temp		
R-squ.	0.1906	0.1929
Adj. R-squ.	0.1747	0.1737
F-Stat	0.0000	0.0000
D.W.	1.9379	1.9383
LM test	0.7237	0.7110
White test	0.0000	0.0000
AIC	-3.0428	-3.0737
SC	-2.9727	-2.9685

*** indicates 1% significance, ** 5% significance and * 10% significance.

cant respectively at 1% and 5% in row (1) which improves the quality of this regression.

What concerns environmental policy indicators, the *banfr* variable is significant at 5% in row (1). Its positive sign suggests the French restriction on banking between Phase I and II contributes to the decline of EUA price changes toward zero until the end of Phase I. The *banpl* variable is not significant. The EPR ratio is positive and significant in row (1) at 1%. Allowance price changes therefore react to the EPR ratio with the expected sign, *i.e.* the higher (lower) the expected allowance scarcity the higher (lower) the allowance price.

Coefficient estimates are robust to the introduction of energy market shocks. Results for *banfr* and *epr* in row (2) are consistent with those in row (1). *ngas* and $ngas(-1)$ affect positively EUA price changes at 5%, which is in line with previous literature on EUA price determinants (Mansanet-Bataller *et al.* (2007)). The fact that *temp* is not significant suggests abnormal climatic events with respect to seasonal average should be used instead of the European temperature index here.

5.2 "Before the compliance break"

Regression results for the sub-period "before the compliance break" are given in Table 3. Similarly to the full period, calculations of the confidence intervals lead to the rejection of the Hotelling rule. At this point in time, the only environmental policy indicator is the *epr* variable, which is not significant in row (3). This result suggests agents were not trading allowances based on the expected allowance scarcity. Despite the introduction of *ngas* and $ngas(-1)$ at 1% significance with the expected sign, the *epr* variable remains non significant in row (4).

While allowance price changes seemed to react to other energy market shocks, it appears more difficult to ascertain the effects of the banking restriction before the compliance break for two main reasons. First, discussions on the banking provisions were still under way between France, Poland and the EC. Second, market participants had incomplete information about the

Table 3: Hotelling-CAPM Model: "Before the compliance break" results

	(3)	(4)
$p_t(-1)$	-0.7943***	-0.7409***
	(0.0828)	(0.0921)
ma(1)	0.9853***	0.9822***
	(0.0206)	(0.0207)
Constant	-0.0141	-0.0099
	(0.0137)	(0.0123)
$r_t^f\ p_t$	-0.0011	-0.0049
	(0.0053)	(0.0059)
$(r_t^m - r_t^f)\ p_t$	-0.0001	-0.0009
	(0.0033)	(0.0039)
$\mathrm{p}_t$min	-0.0246**	-0.0385***
	(0.0114)	(0.0103)
epr	0.0393	0.0317
	(0.0323)	(0.0282)
ngas		0.0021***
		(0.0007)
ngas(-1)		0.0022***
		(0.0007)
$\mathrm{p}_t$max		
brent		
temp		
R-squ.	0.1245	0.2448
Adj. R-squ.	0.0889	0.2051
F-Stat	0.0008	0.0000
D.W.	1,9744	1.8448
LM test	0.8199	0.2698
White test	0.0053	0.5200
AIC	-4.6297	-4.7535
SC	-4.4843	-4.5727

*** indicates 1% significance, ** 5% significance and * 10% significance.

net short/long positions at the installation level which were only revealed by the release of 2005 verified emissions.

5.3 "After the compliance break"

Regression results for the sub-period "after the compliance break" are given in Table 4. Calculations of the confidence intervals also yield to the rejection of the Hotelling rule. The $banfr$ variable is positive and significant at 1% in row (5) which, similarly to the full sample, suggests the French ban on banking contributes to the explanation of low EUA prices until the end of Phase I. The EPR ratio becomes significant again at 5% and positive in row (5) suggesting market participants pay more attention to the expected allowance scarcity revised after the 2005 compliance. Those results are stable in row (6). The introduction of the $brent$ variable at 5% significance is similar in sign to previous literature (Mansanet-Bataller *et al.* (2007)).

5.4 Discussion

5.4.1 On the failure of the Hotelling rule

The failure of the Hotelling rule during Phase I of the EU ETS is not worrying in itself. Recent empirical applications state even if it fails such analysis still brings a better understanding of the intertemporal scheduling of the resource use overtime (Heal (2007)). In the context of the EU ETS, the rejection of the Hotelling rule implies EUA prices do not adequately reflect abatement costs at the installation level during 2005-2007. Indeed, Helfand *et al.* (2006) who also reject the Hotelling rule for the SO_2 allowance price pattern state "*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 emission regulation*". As noted previously, the efficiency of allowance trading is linked to the authorization of flexibility instruments where agents may trade allowances not only spatially but also through time, such as full banking and restricted borrowing (Schennach (2000), Kling & Rubin (1997)). With-

Table 4: Hotelling-CAPM Model: "After the compliance break" results

	(5)	(6)
$p_t(-1)$	-0.3135**	-0.2443*
	(0.1584)	(0.1409)
ma(1)	0.7123***	0.6434***
	(0.1440)	(0.1274)
Constant	-0.0366***	-0.0351***
	(0.0142)	(0.0135)
$r_t^f\ p_t$	-0.1904	-0.1994
	(0.1507)	(0.1454)
$(r_t^m - r_t^f)\ p_t$	0.0054	0.0129
	(0.0169)	(0.0169)
$p_t$min	-0.1306***	-0.1211***
	(0.0245)	(0.0293)
epr	0.1343**	0.1312**
	(0.0586)	(0.0559)
banfr	0.0310***	0.0359***
	(0.0110)	(0.0106)
brent		0.0062**
		(0.0028)
$p_t$max		
banpl		
ngas		
temp		
R-squ.	0.2570	0.2754
Adj. R-squ.	0.2300	0.2456
F-Stat	0.0000	0.0000
D.W.	1.9417	1.9670
LM test	0.5502	0.7227
White test	0.0002	0.0002
AIC	-3.0390	-3.0554
SC	-2.9041	-2.9054

*** indicates 1% significance, ** 5% significance and * 10% significance.

out such provisions, market prices do not reflect opportunity costs leading to an efficient choice of abatement measures (Schleich *et al.* (2006)). Kronenberg (2006) provides other reasons to justify this failure, for instance by paying attention to the fact that allowances are characterized by a costless extraction or by focusing on strategic interactions between firms[26].

5.4.2 On institutional learning

Our results suggest an increasing influence of the environmental policy constraint on EUA price changes. This evidence may be approximated first by the significance of the EPR ratio. Before the price adjustment on April, 2006 allowance trading may be characterized as uncertain with heterogeneous expectations related to the EUA price pattern and only the release of 2005 verified emissions gave industrials a hint about their net short/long positions. After the compliance 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 again. Second, we may deduce from official communications between France and the EC that the French ban on banking significantly affected allowance price changes and contribute to a sharper explanation of low allowance prices. As EUA price changes are statistically and significantly affected by institutional events such as the April, 2006 structural break, the French ban on banking and the EPR indicator of a low allowance scarcity, a main finding of our tests lies in the evidence of institutional learning within Phase I.

5.4.3 On the influence of energy markets

As stated by Mansanet-Bataller *et al.* (2007), EUA prices are affected by Brent and Natural gas market shocks. However, the *temp* variable is not significant. Our point is to show the influence of environmental policy indicators is robust to the introduction of energy market shocks: signs and coefficient

[26]For instance, lobbying activites may take place within each allocation plan to extract more allowances from the regulator based on past emissions as a monopoly rent.

estimates for the $banfr$ dummy and the epr ratio remain significant in full period (row 3) and after the break (row 6).

6 Conclusion

This analysis estimates the impact of banking restrictions on EUA prices. Beginning at 8 € on January 1, 2005 allowance prices initially rose to 20-30 €, and have been declining steadily since the disclosure of 2005 verified emissions on April, 2006. Previous literature identified among the main explanations of this price pattern over-allocation concerns, early abatement efforts in 2005 and possibly decreasing abatement costs in 2006 due to the interaction with energy markets and climatic events (Buchner & Ellerman (2007), Mansanet-Bataller *et al.* (2007)). Our work demonstrates banking and borrowing provisions adopted during Phase I and II may also contribute to the explanation of low EUA prices.

First, with unrestricted banking within Phase I, we give evidence that allowance prices do not reflect adequately abatement costs leading to abatement efforts based on a Hotelling-type analysis (Schennach (2000), Slade & Thille (1997), Helfand *et al.* (2006)). With regard to high allowance prices until the compliance break, early abatement occurred in the EU ETS to meet the cap requirements. After the 2005 compliance and the correction of the expectation error concerning the amount of abatement required to comply with the cap, the restriction on inter-period banking limited additional abatement[27].

Second, with restricted banking between Phase I and II, we estimate the effects of two environmental policy indicators related to banking provisions on EUA prices. The Ellerman & Parsons ratio is used to measure the probability of allowance shortage at the end of Phase I expected by market participants. French official communications to the European Commission concerning banning banking between 2007 and 2008 in its NAP II are used as

[27]Indeed, as stated by Ellerman & Montero (2007) on the evaluation of the US SO_2 program, "*when allowed in phased-in cap-and-trade programs, banking can be expected to produce more abatement and higher allowance prices in the early phases of the program*".

a dummy variable. Before the compliance break, EUA prices are not affected by the expected allowance scarcity at the end of 2007. After the compliance break, market participants form their anticipations more accurately in a context of a low environmental policy constraint and the impossibility to transfer allowances from Phase I to Phase II. Both indicators become significant in explaining the low EUA price pattern, as for the full period sample. These results are robust to the introduction of energy market shocks.

Considering Phase I as a learning period, these results give insight into the possible sacrifice of the banking instrument to limit the transfer of design inefficiencies in Phase II. Finally, for Member States to take advantage of the banking provision in longer-term mitigation plans, the publication of the net amount of allowances either banked or borrowed at the end of each compliance period by the European Commission may be of precious use.

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Appendix

A graph of the rates of return for 3 Months-Euribor and Dow Jones EURO STOXX 50 is given in Figure 3. Table 5 shows descriptive statistics for the energy price series under consideration with SE the standard errors, $Skew.$ the skewness, $Kurt.$ the kurtosis and N the number of observations.

	Mean	Median	Max.	Min.	SE	Skew.	Kurt.	N
Full period								
p_t	-0.009	0.000	0.297	-0.437	0.056	-1.332	14.708	492
brent	0.001	0.008	3.757	-2.973	1.068	-0.018	2.797	492
ngas	-0.001	-0.145	11.542	-10.570	1.672	0.997	14.809	492
Before the compliance break								
p_t	0.001	0.001	0.085	-0.134	0.025	-1.044	8.775	208
brent	0.015	-0.006	3.757	-2.827	1.066	0.165	3.024	208
ngas	-0.007	-0.298	11.542	-10.570	1.950	1.056	14.120	208
After the compliance break								
p_t	-0.017	-0.008	0.169	-0.288	0.064	-0.929	6.122	241
brent	-0.017	0.013	2.151	-2.052	0.822	-0.080	2.602	241
ngas	0.016	-0.010	7.206	-6.844	1.484	0.736	11.159	241

Table 5: Descriptive Statistics*
*for the EUA first log-differenced price series, the brent and natural gas price series computed as forecast errors.

Robustness checks

As noted previously, adding energy variables to the model serves as a first robustness check for coefficient estimates. Concerning the choice of the rate of return of a diversified portfolio, the inclusion of the Euronext 100 Index instead of the Dow Jones EURO STOXX 50 does not change the results since financial market places are strongly correlated. The Hotelling rule is still rejected in all models. The determination of the structural break is further proofed by a Chow breakpoint, which rejects the null hypothesis that the sample does not contain a structural break at a 5%. When the White test shows evidence of heteroskedasticity, a GARCH(p,q) model of order 1 has been implemented using Bollerslev Wooldrige robust standard errors and covariance for each period. GARCH coefficients are stable with significant estimates in the mean and variance equations. Since both estimation techniques yield similar results, we present only NW-OLS coefficients to simplify the exposition. A journal of those results may be obtained upon request to the authors.

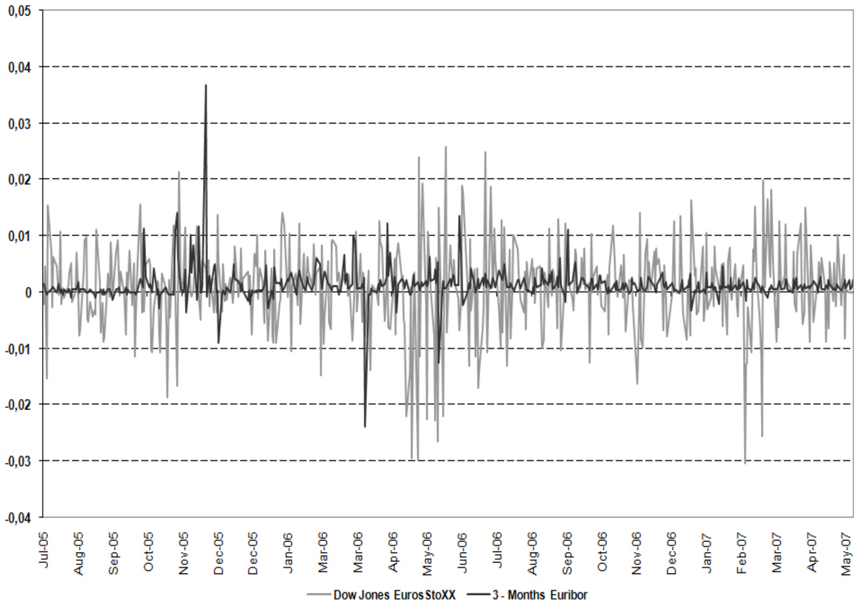

Figure 3: Rates of return for 3 Months-Euribor and Dow Jones EURO STOXX 50 in percentage points at daily rates
Source: Banque de France and Euronext

References

Buchner, B., & Ellerman, E.D. 2007. The European Union Emissions Trading Scheme: Origins, Allocation, and Early Results. *Review of Environmental Economics and Policy*, **1**, 66–87.

Cason, T.N., & Gangadharan, L. 2004. *Emissions Variability in Tradable Permit Markets with Imperfect Enforcement and Banking*. Department of Economics, Purdue University, West Lafayette, Indiana, April.

Ehrhart, K.M., Hoppe, C., Schleich, J., & Seifert, S. 2005. The Role of Auctions and Forward Markets in the EU ETS: Counterbalancing the Cost-Inefficiencies of Combining Generous Allocation with a Ban on Banking. *Climate Policy*, 31–46.

Ellerman, A.D., & Montero, J.P. 2002. The Temporal Efficiency of SO2 Emissions Trading. *CMI Working Paper*, **13**. Cambridge MIT Institute.

Ellerman, A.D., & Montero, J.P. 2007. The Efficiency and Robustness of Allowance Banking in the U.S. Acid Rain Program. *Energy Journal*, **28**(4), 205–233.

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.

Godby, R.W., Mestelman, S., Muller, R.A., & Welland, J.D. 2000. Emissions Trading with Shares and Coupons when Control of Discharges is Uncertain. *Journal of Environmental Economics and Management*, **32**.

Grubb, M., & Neuhoff, K. 2006. Allocation and Competitiveness in the EU Emissions Trading Scheme: Policy Overview. *Climate Policy*, **6**, 7–30.

Heal, G. 2007. A Celebration of Environmental and Resource Economics. *Review of Environmental Economics and Policy*, **1**, 7–24.

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

Hotelling, H. 1931. The Economics of Exhaustible Resources. *Journal of Political Economy*, **39**, 137–175.

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.

Lee, J., & Strazicich, M.C. 2003. Minimum LM Unit Root Test with Two Structural Breaks. *Review of Economics and Statistics*, **85**(4), 1082–1089.

Leiby, P., & Rubin, J. 2001. Intertemporal Permit Trading for the Control of Greenhouse Gas Emissions. *Environmental and Resource Economics*, **19**, 229–256.

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

Maeda, A. 2004. Impact of Banking and Forward Contracts on Tradable Permit Markets. *Environmental Economics and Policy Studies*, **6**, 81–102.

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.