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Andrea Beltratti, Paolo Colla and Anna Cretì

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IEFE - The Center for Research on Energy and Environmental Economics and Policy at Bocconi University
Via Guglielmo Röntgen, 1 - 20136 Milano
tel. 02.5836.3820 - fax 02.5836.3890
www.iefe.unibocconi.it – iefe@unibocconi.it

Does expected supply affect the price of emission permits? Evidence from Phase I in the European system

Andrea Beltratti
Università Bocconi, Finance Department

Paolo Colla
Università Bocconi

Anna Cretì
Università Bocconi, Economics Department and IEFE

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Abstract

Does current and future supply affect the market price of pemits? The answer should be positive as the market itself was created by the governments that also control the supply. However, governments themselves may be uncertain about the relation between supply and price and may go through a learning period. Do investors believe in the announcements of governments about the future supply? We find the answer was positive at least regarding Phase I of the Europen system, where empirical evidence about a current excess supply of permits was offset by announcements of a future excess demand.

JEL Classification: D21, G13, Q50

Keywords: emission allowances, futures

1 Introduction

The 1997 Kyoto Protocol has proposed three market mechanisms to push the private sector towards discovering the most efficient ways to curb emissions of CO_2: International Emission Trading, Joint Implementation (JI) and Clean Development Mechanism (CDM). In 2005 the EU has launched a market for trading permits to emit CO_2 (EU emission allowances or EUAs). The European market for emission trading (EU ETS) represents a very successful example. JI and CDM are somewhat active and interrelated with the EU market, but quantitatively less important (see Capoor and Ambrosi [6]). However, prices in the EU market have been very volatile.

For the permits market to develop in the long run, there needs to be a serious public commitment to force private agents to respect limits which effectively constrain emissions. Only in this way it is possible to create a scarcity that is reflected into positive allowance prices. The EU market was set with this purpose in mind. The goal was to force major polluters (especially in the energy, metals and minerals sectors) to phase down emissions gradually over time, leaving to firms the choice of the best way to achieve the target. Emitters who are able to efficiently decrease emissions can sell some of their permits on the market; emitters who cannot efficiently decrease emissions have to buy extra permits. It is also possible to comply by using CERs (Certified Emission Reduction carbon credit, derived from CDM projects) and ERUs (Emission Reduction Unit carbon credit, derived from JI projects) but within given proportions decided by each country, generally up to the limits of 10%.

The EU ETS has been organized in three phases: Phase I in 2005-2007, Phase II in 2008-2010, Phase III would be the permanent arrangement starting in 2011. In 2005 major emitters were freely allocated an initial amount (larger than 2 billion) of permits. They were then free to trade these permits in the market, knowing that they would have to hold an amount of permits corresponding to the amount of emissions of the previous year at certain verification times. Lacking this compliance, companies would have to pay sanctions (100 €/ton plus the purchase of the missing permits in Phase II and 40 €/ton plus the purchase of the missing permits in Phase I). An identical new supply was given every year to the same sources.

The market involves both spot and futures contracts, but there exists an important difference between Phase I and Phase II as to the link between the spot and the futures market. In Phase I investors and firms could trade futures contracts with an expiry date beyond Phase I. , it was impossible to arbitrage between spot and futures prices as the underlying was not traded in Phase I. In fact, according to the rules set by the Directive 2003/87/EC, permits released in Phase I could not be used in Phase II, a situation known as "lack of bankability". Emission permits are however bankable between Phase II and Phase III, as established by the new trading EU Directive (2009/89/EC).

It was already noted that the European market rests on an important element of trust in the public sector.[1] The latter has in fact created a market from scratch, on the basis of the observation that the private sector would emit too much CO_2 and would not take negative pollution externalities into account. The limited possibility on the part of the environmental system to absorb CO_2 without major changes in the climate is equivalent to saying that there is scarcity in the capacity to absorb emissions. The interaction of a scarce capacity to absorb emissions and an excessive desire to emit on the part of producers and consumers represents the prerequisite for a market.

Since the beginning, the market has had to recognize substantial uncertainties about the level of supply. For example, even in Phase II, there were indecisions about the possibility to use CERs and ERUs to comply in Phase III. According to some proposals, any spare capacity in the use of CERs and ERUs could have been used in Phase III but limiting the future use of CERs and ERUs. Another source of uncertainty was the inclusion of new important sectors, for example the aviation industry. Also relevant is the issue of the supply of new permits at the beginning of Phase III, which, given bankability, affects prices in Phase II. For example, EUA allocations were 2,270 million tonnes for 2005-2007 (versus actual emissions of about 2,000 million) and 2,080 in 2008-2012. The level of supply in Phase III will depend on the commitment of the European governments to reaching the target. Important is also technological uncertainty about the costs of CO_2 abatement and the development of alternative technologies. Finally, in Phase I there was uncertainty about the supply of permits in

[1] The advantages of permits schemes in terms of pollution control may be undermined by political uncertainties regarding trading and banking provisions (see Hahn [10]), inasmuch as the performance of emission permits is crucially linked to the commitment of regulators (see, among others, Ben-David et al. [4], Laffont and Tirole [12], Leston [13] and Stavins [21]).

Phase II, and, initially, also about the relation between allowances demand and supply.

Some empirical literature has analyzed the determination of emission permits prices. Alberola and Chevallier [1] show that the Hotelling rule (prices increasing at the rate of interest under certainty) does not hold during Phase I; moreover they claim that the lack of bankability undermined the ability of the market to provide an efficient price signal for emissions abatement (see also Milounovich and Joyeux [17] and Uhrig-Homburg and Wagner [22]). Mansanet-Bataller, Pardo and Valor [16] study the relevance of energy prices and weather variables on the determination of spot prices and find that the former variables are more relevant than the latter. Alberola, Chevallier and Chèze [3] find two structural breaks in Phase I (April 2006 and October 2006) subsequent, respectively, to the disclosure of emissions and the announcement of new allocations for Phase II, and find that prices react also to unexpected weather events. Borak et al. [5] model the convenience yield (the difference between the final value of the spot price and the corresponding futures price) as a function of the spot price and the variance of the spot price. Using data for the period October 4, 2005 to September 29, 2006 they find that the market has moved from backwardation to contango, and document many changes in the term structure of volatilities. They also find a positive impact of the spot price on the convenience yield and a negative impact of variance.

In this paper we develop a model for the joint determination of spot and futures prices, and derive an equation to explain the difference between the Phase I spot price and the futures price with expiration in Phase II. We consider a market where both compliance (firms) and non-compliance agents (speculators) trade emission permits at two consecutive trading rounds. Firms produce a homogeneous good and, in doing so, they emit pollutants. Reducing emissions via abatement is costly. At the beginning of each round, each firm is allocated emission allowances and has to buy (or can sell) permits to fill the gap between net emissions, i.e. emissions minus abatement, and its endowment via spot transactions. Firms cannot bank or borrow permits between the two dates, consistently with the EU ETS lack of bankability between Phase I and Phase II. However, during the first round, firms can also trade allowances via futures contracts for delivery at the second date. Speculators enter into futures trade, and profit by the expected price differential between futures prices and expected spot prices. The interplay between risk-averse compliance and non-compliance agents in our model follows the approach taken by Maeda [15] and, more recently, Colla, Germain and van Steenberghe [7]. We innovate with respect to both papers by explicitly considering uncertainty about future environmental policy, which adds to the production risk faced by firms: within a market structure similar to ours, Maeda [15] postulates that firms' emissions to be driven by a common factor, while Colla, Germain and van Steenberghe [7] develop a two-date model with bankable permits and no futures market. According to the testable version of our theoretical model, the convenience yield for Phase I depends on abatement costs as well as some nonlinear variables deriving from the interaction between abatement costs and elements like the spot price and the covariance between financial wealth and production. The model further allows identification of a coefficient measuring the future excess supply perceived by the market. We use daily data for Phase I to estimate the empirical counterpart to this equation and we find that market participants were willing to believe the announcement of the EC about a future relative reduction in the supply of permits, regardless of the empirical evidence about a current excess supply.

The plan of the paper is as follows: after this introduction, Section 2 first describes the economic model and then studies the determination of prices in equilibrium; Section 3 presents the empirical analysis and Section 4 concludes.

2 Environmental policy and convenience yields

2.1 Model setup

Our main goal is to understand how uncertainty about environmental policy influences allowance prices, and how it interplays with production. To this aim, we consider a model with two dates, $t = 1, 2$, where each date represents one EU ETS Phase.

Allowance markets. Trading activity takes place on both spot and futures markets. The spot market is open at both dates with permits prices given by p_1 and p_2. At date 1 market participants can enter futures transactions to trade permits for date 2 delivery at the price F. Banking (spot) permits across dates is not allowed, consistently with the interphase rule applied within the EU ETS.

Agents. There is a continuum of agents that are price takers in all markets and risk averse. There are two types of market participants: compliance (firms) and non-compliance agents (speculators). We let λ be the measure of firms, while $1-\lambda$ denotes that of speculators.

Each firm, indexed by i, emits pollutants at both dates, and emissions are subject to regulation via a trading mechanism. At date t, firm i emissions in the absence of environmental policy (so called BAU emissions) are given by e_{it}^{B}. Firm i freely receives an endowment of permits from the regulator in each phase, $\bar{e}_{it}$. We further define $\Delta e_{it} = e_{it}^{B} - \bar{e}_{it}$ as firm i permits shortage in the absence of abatements. The abatement of firm i during phase t is a_{it}, so that $e_{it}^{B} - a_{it}$ corresponds to each firm actual emissions. The abatement cost function, $C_i\left(a_{it}\right)$, is increasing and convex in a_{it} and we further specialize it to take the following form:

A.1. The abatement cost function is quadratic

$$C_i\left(a_{it}\right) = \frac{1}{2}c_i a_{it}^2. \tag{1}$$

Assumption A.1 is imposed mainly for tractability. Our results will be qualitatively unaffected if we considered: 1) time-varying marginal abatement costs, c_{it}, in (1) and/or 2) a second order Taylor appoximation to the abatement cost function, i.e. $C_i\left(a_{it}\right) \simeq a_{it} + \frac{1}{2}c_i a_{it}^2$.

Each firm needs to buy (or can sell) permits to fill the gap between actual emissions, $e_{it}^{B} - a_{it}$, and its endowment, $\bar{e}_{it}$, via spot transactions at price p_t. In other words, each firm needs to purchase on the spot market a number of permits equal to its shortage, Δe_{it}, minus abatements, a_{it}. Finally, firms' payoffs reflect the cash settlement of futures transactions at price F. Firm i profits read as

$$\Pi_i = -\sum_{t=1}^{2} \frac{1}{2}c_i a_{it}^2 + \sum_{t=1}^{2} p_t\left(a_{it} - \Delta e_{it}\right) + f_i\left(p_2 - F\right), \tag{2}$$

where $f_i > 0$ denotes a long futures position.

Non-compliance agents' payoffs account for two components. Each speculator, indexed by j, has wealth w_j originated outside of the permits market, say labour income or financial wealth. Moreover, speculator j can buy/sell permits forward, so that his profits are

$$\Pi_j = w_j + f_j\left(p_2 - F\right), \tag{3}$$

where $f_j > 0$ corresponds to a long futures position.

Economy. For notational purposes, we define the aggregate counterparts of the above variables. At each date, the total BAU emissions in the economy are $E_t^B = \int_0^\lambda e_{it}^B di$, while the sum of permits endowments over all firms represents the environmental objective, $\bar{E}_t = \int_0^\lambda \bar{e}_{it} di$. The aggregate permits shortage during phase t is then $\Delta E_t = E_t^B - \bar{E}_t$. For the environmental policy to be effective in reducing emissions, the aggregate shortage has to be negative. Finally, we let $W = \int_\lambda^1 w_j dj$ be the aggregate wealth.

Uncertainty. Economic uncertainty comes from three sources: BAU emissions, allowance endowments and financial wealth. Each firm sets abatements a_{it} –which in turn determine permit trading activity in the spot market– under certainty. However, futures contracts are signed at date 1 before uncertainty about date 2 variables is resolved: each firm chooses f_i before knowing BAU emissions, e_{i2}^B, and its permits endowment, $\bar{e}_{i2}$, while each speculator sets f_j before observing the realization of his labour income, w_j.

The following two assumptions jointly describe the uncertainty related to BAU emissions:

A.2. Aggregate production, Y_2, follows a Gaussian random walk process

$$Y_2 = Y_1 + \varepsilon, \tag{4}$$

with $\varepsilon \sim \mathcal{N}.i.d. \left(0, \sigma_Y^2\right)$.

Assumption A.2 is mainly imposed for illustrative purposes, since what we require from the production process is that it prescribes Y_2 to be normally distributed –conditional on date 1 variables. Together with quadratic abatement cost function (see assumption A.1) normality ensures we find closed form solutions, as we shall explain. The random walk process in eq. (4) can therefore be easily replaced imposing, say, an AR process or a linear univariate model with more lags. Despite its simplicity, the process (4) is not unreasonable from an empirical perspective as well.[2]

[2]Starting from Nelson and Plosser [18], a large literature has investigated the non-stationarity of macroeconomic series with special attention to unit-roots in real GDP series, and the conclusion is that GDP levels are non-stationary (see Fleissig and Strauss [9] and Rapach [19] for evidence on OECD countries).

A.3. Firm i BAU emissions reflect aggregate production as well as an idiosyncratic component according to the single-factor structure

$$e_{i2}^{B}=\beta_{i}Y_{2}+\varepsilon_{i2}, \tag{5}$$

where $\varepsilon_{i2}\sim\mathcal{N}\left(0,\sigma_{\varepsilon}^{2}\right)$ with $cov\left(\varepsilon_{i2},\varepsilon\right)=0$, $\forall i$, and $cov\left(\varepsilon_{i2},\varepsilon_{j2}\right)=0$ for $i\neq j$.

The main idea behind assumption A.3 is that CO_2 emissions are driven by economic activity. As a consequence, aggregate production constitutes a common factor affecting emissions for all installations. One can easily replace assumption A.3 to accommodate for multiple risk factors, without qualitatively changing our findings. For instance, the empirical literature underscores that energy prices are the most important drivers for EUA prices between 2005-2007 (see Alberola, Chevallier and Chèze [3] and Mansanet-Bataller, Pardo and Valor [16] among others). This evidence is consistent with the fact that regulated emitters mainly included power generators during the EU ETS Phase I. We could add energy prices (oil, gas and coal) as well as weather variables (air temperature and rainfall precipitation) on the RHS of eq. (5) to incorporate specific factors that are likely to affect energy consumption without qualitatively changing our results. Note that eq. (5) yields aggregate BAU emissions as

$$E_{2}^{B}=\beta Y_{2}+\int_{0}^{\lambda}\varepsilon_{i2}di, \tag{6}$$

where we set $\beta=\int_{0}^{\lambda}\beta_{i}di$. In general, $\beta<1$ as long as not all productive sectors are included in the cap-and-trade scheme, as is the case for the EU ETS.

We now turn to the second source of uncertainty firms face:

A.4. Firm i allowances are distributed according to a pro-quota allocation of the overall environmental objective, $\bar{E}_2$, i.e.

$$\bar{e}_{i2}=\gamma_{i}\bar{E}_{2}, \tag{7}$$

where $\bar{E}_{t}\sim\mathcal{N}\left(\mu,\sigma^{2}\right)$ with $cov\left(\bar{E}_{2},\varepsilon\right)=\sigma_{E,Y}$.

The γs describe the sharing rule according to which permits are distributed to firms. For example, during Phase I, most European countries have essentially established a grandfathering criterion where the free allocation of allowances reflected the amount of pollution over several years preceding the EU

ETS.[3] Since permits are allocated to regulated polluters only, the γs add up to unity $\int_0^\lambda \gamma_i di = 1$. According to assumption A.4, total allowances are correlated with total production and $\sigma_{E,Y}$ which describes the regulator's attitude towards environmental protection. A lax environmental policy would be characterized by $\sigma_{E,Y} > 0$, since any increase in pollution due higher aggregate production is accommodated by raising the amount of allowances. On the contrary, $\sigma_{E,Y} < 0$ corresponds to a tight environmental policy.

The last source of randomness in the economy pertains to wealth generated outside the permits markets.

A.5. Speculator j financial wealth corresponds to a fraction η_j of the aggregate wealth

$$w_j = \eta_j W \tag{8}$$

where $W \sim \mathcal{N}\left(\mu_W, \sigma_W^2\right)$ with $cov\left(W, \varepsilon\right) = \sigma_{W,Y}$ and $cov\left(W, \bar{E}_2\right) = cov\left(W, \varepsilon_{i2}\right) = 0$, $\forall i$.

In general, we allow speculators' aggregate wealth to be correlated with other economic variables, most notably date 2 production. Coupled with eq. (6), assumptions A.5 implies that w_j is correlated to date 2 total BAU emissions, E_2^B. This leaves some room for speculators' to hedge their financial risk via futures transactions since w_j is correlated with the aggregate permits shortage ΔE_2, which is the driver of spot permits prices as we shall explain below. Within a general equilibrium perspective, aggregate wealth would coincide with aggregate production. However, since we are dealing here with a partial equilibrium analysis, we leave open the possibility for this correlation to be different from perfect. In

[3] The first ETS Directive mandates that 95% of the total emission allowances were to be allocated for free. In this setting two possible allocation methodologies exist: benchmarking and grandfathering. Benchmarking is an allocation mechanism according to which installations would receive allowances according to some benchmark emission rate times an indicator of the installation's level of economic activity expressed as quantities of output or inputs (i.e. energy consumption). This method is advocated as a means of rewarding installations with relatively low emission rates and pushing those with comparable high emission rates. However this mechanism has been rarely adopted in the first phase (2005-2007) because of the heterogeneity of production processes, which reflects differences in final product and local circumstances more than those in efficiency, and due to the lack of pre-existing standards that could serve as benchmark. Furthermore, allocation based on benchmarks would have been too far below recent emissions to gain widespread acceptance. As a consequence grandfathering became the reference point, whereby allowances would be allocated according to past emission levels.

the remainder, we will let $\eta = \int_0^\lambda \eta_j dj$ denote the fraction of aggregate wealth that collectively accrues to speculators. Note that $\eta < 1$ accommodates the fact that some speculators might not participate in the permits markets. We expect this to be the more realistic case, since some financial institutions as well as hedge funds are already active in the EU ETS while the participation of individual investors at this stage is still limited (see Convery and Redmond [8]).

Finally, we are left with specifying how uncertainty affects agents' decisions:

A.6. All agents are risk-averse as captured by the following expected utility

$$E\left[U_k\left(\Pi_k\right)\right] = E\left(\Pi_k\right) - \left(2\tau_k\right)^{-1} V\left(\Pi_k\right) \tag{9}$$

where k represents either i or j, and $\tau_k > 0$ is agent k risk tolerance coefficient.

The representation (9) can be readily obtained coupling CARA preferences together with normality of the underlying payoff distribution (see Lintner [14]).

Sequence of decisions. At each date t, firms choose abatement a_{it} after observing their date t endowment, $\bar{e}_{it}$, and BAU emissions, e_{it}^B. Moreover, at date 1 both firms and speculators decide their futures position, f_i and f_j respectively, for delivery at the second date. The spot prices p_1 and p_2 as well as the futures price F are endogenous and determined by market clearing. Figure 1 illustrates the sequence of decisions.

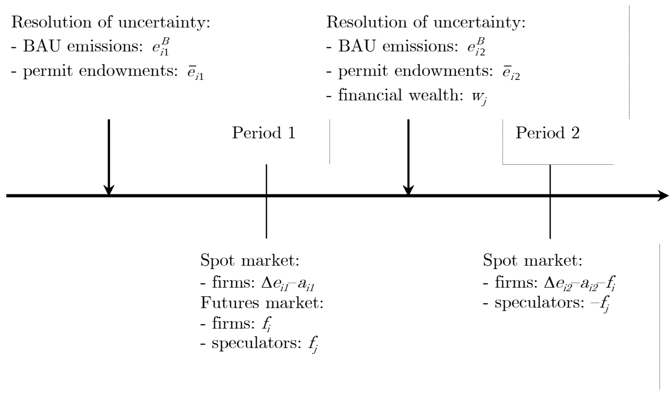

Figure 1. Sequence of decisions.

2.2 Equilibrium

We solve for futures positions $\left(f_i^*, f_j^*\right)$, abatements (a_{i1}^*, a_{i2}^*) and prices (p_1^*, p_2^*, F^*) in equilibrium by backward induction.

Date 2. Firms face no uncertainty about $\bar{e}_{i2}$ and e_{i2}^B. Each firm i chooses abatements solving the program

$$a_{i2}^* \in \arg\max_{a_{i2}} -\frac{1}{2}c_i a_{i2}^2 + p_2\left(a_{i2} - \Delta e_{i2}\right).$$

Optimality requires equalization between marginal abatement costs and the permits spot price, thus yielding

$$a_{i2}^* = \frac{p_2}{c_i}. \tag{10}$$

Market clearing requires $\bar{E}_2 = \int_0^\lambda \left(e_{i2}^B - a_{i2}^*\right) di$, which together with eq. (10) gives the equilibrium permit price, p_2^*, as

$$p_2^* = \frac{\Delta E_2}{C}, \tag{11}$$

where we have set

$$C = \int_0^\lambda c_i^{-1} di.$$

Eqs. (10) and (11) describe the equilibrium prevailing at date 2. According to eq. (11), permits prices increase in the aggregate shortage of permits and in marginal abatement costs. The regulator can create allowance scarcity by issuing less permits relative to total BAU emissions, so that $\Delta E_2 > 0$. Each firm would then reduce its emissions, and environmental quality would improve.

The first two moments of date 2 prices can be readily calculated from eq. (11) as

$$E\left(p_2^*\right) = C^{-1}\left[\beta E\left(Y_2\right) - \mu\right] \tag{12}$$

and

$$V\left(p_2^*\right) = C^{-2}\left[\beta^2\sigma_Y^2 + \lambda\sigma_\varepsilon^2 + \sigma^2 - 2\beta\sigma_{E,Y}\right]. \tag{13}$$

According to eq. (12) the expectation of future prices increases with date 2 expected production, since this increases each firm BAU emissions, while an increase in the expected number of permits makes the environmental constraint more lax, and prices tend to decrease. As for the second moment, eq.

(13) reveals that uncertainty about both date 2 BAU emissions as well as the overall environmental objective increase the variance of future prices. Interestingly, eq. (13) uncovers tightness as another channel through with the regulator affects price volatility. For instance, permit prices are more volatile whenever the regulator pursues a tight policy issuing fewer permits whenever total production –and thus unregulated pollution– rises ($\sigma_{E,Y} < 0$).

Date 1. Speculators are uncertain about their future wealth, w_j, as well as the next period permits spot price, p_2^*. By means of eqs. (3) and (9), each speculator j chooses his futures position according to

$$f_j^* \in \arg\max_{f_j} \eta_j \mu_W + f_j \left[E\left(p_2^*\right) - F\right] - \left(2\tau_j\right)^{-1} \left[f_j^2 V\left(p_2^*\right) + 2 f_j cov\left(w_j, p_2^*\right)\right], \tag{14}$$

which gives

$$f_j^* = \frac{1}{V\left(p_2^*\right)} \left\{\tau_j \left[E\left(p_2^*\right) - F\right] - cov\left(w_j, p_2^*\right)\right\}. \tag{15}$$

Eq. (15) highlights how futures can be used for both speculative and hedging purposes. Non-compliance agents choose a long futures position whenever: 1) the spot price is expected to be above the futures price (speculative component) and/or 2) permits provide insurance against future income fluctuations (hedging component). By means of eq. (15) we can assess how the environmental policy affects the speculators' demand for future contracts. Consider the case in which income is positively correlated with production ($\sigma_{W,Y} > 0$) and thus with BAU emissions. Other things equal, speculators cut down futures position since permits do not help in hedging income risk. Moreover, in case the regulator pursues a tight policy, permits prices are more volatile as revealed by eq. (13), depressing f_j^* even further.

At date 1, each firm faces uncertainty about its future permits shortage, Δe_{i2}, and consequently the equilibrium price p_2^*. Substituting equilibrium abatements a_{i2}^* (see eq. (10)) into firm i profits in eq. (2) yields

$$\Pi_i = -\frac{1}{2} c_i a_{i,1}^2 + p_1 \left(a_{i1} - \Delta e_{i1}\right) + \frac{\left(p_2^*\right)^2}{2 c_i} - p_2^* \Delta e_{i2} + f_i \left(p_2^* - F\right), \tag{16}$$

and the corresponding first two moments

$$E\left(\Pi_i\right) = -\frac{1}{2} c_i a_{i1}^2 + p_1 a_{i1} + f_i \left[E\left(p_2^*\right) - F\right] + \varphi, \tag{17}$$

and

$$V(\Pi_i) = f_i^2 V(p_2^*) + f_i \left\{ c_i^{-1} cov \left[(p_2^*)^2, p_2^* \right] - 2cov(p_2^* \Delta e_{i2}, p_2^*) \right\} + \xi, \tag{18}$$

where φ and ξ do not depend on either a_{i1} or f_i.[4] Firms set abatements, a_{i1}^*, and futures positions, f_i^*, according to:

$$\left(a_{i1}^*, f_j^*\right) \in \arg\max_{a_{i1}, f_i} E(\Pi_i) - (2\tau_i)^{-1} V(\Pi_i).$$

where $E(\Pi_i)$ and $V(\Pi_i)$ are as in eqs. (17) and (18) respectively. Similarly to the date 2 analysis, optimality w.r. to abatements requires

$$a_{i1}^* = \frac{p_1}{c_i}, \tag{19}$$

so that the equilibrium spot price prevailing at date 1 is

$$p_1^* = \frac{\Delta E_1}{C}. \tag{20}$$

Finally, firm i futures position is given by

$$f_i^* = \frac{1}{V(p_2^*)} \left[\tau_i \left[E(p_2^*) - F \right] - \left\{ (2c_i)^{-1} cov \left[(p_2^*)^2, p_2^* \right] - cov(p_2^* \Delta e_{i2}, p_2^*) \right\} \right]. \tag{21}$$

Comparing eqs. (21) and (15) reveals that both f_i^* and f_j^* include the speculative component – which is driven by the expected price differential $E(p_2^*) - F$. However, a firms' motives behind forward transactions are more articulated than the speculators. This occurs because uncertainty about future spot prices affects firms and speculators in different ways, as revealed by comparing the payoffs in eqs. (3) and (16). reveals.

The equilibrium in the futures market is summarized in the following:

Proposition 1 *The futures market equilibrium is given by trades* $\left(f_i^*, f_j^*\right)$ *and the corresponding price*

$$F^* = E(p_2^*) + \tau^{-1} \left[E(p_2^*) \, cov(\Delta E_2, p_2^*) - cov(\eta W, p_2^*) \right] \tag{22}$$

where τ *is the market risk tolerance:*

$$\tau = \int_0^\lambda \tau_i di + \int_\lambda^1 \tau_j dj. \tag{23}$$

[4] The covariance terms in eq. (18) can be readily computed from the joint distribution of the vector $(\Delta e_{i2}, p_2^*)$, as we show in the appendix (see Lemma 1).

Proposition 1 provides interesting insights since it identifies the determinants of the convenience yield, i.e. the risk premium $F^* - E(p_2^*)$. Such premium is driven by firms' and speculators' hedging motives. When speculators are the sole market participants we have from eq. (22)

$$F^*(\lambda = 0) = E(p_2^*) - \tau^{-1} cov(\eta W, p_2^*), \tag{24}$$

so that the speculators' hedging motives drive the convenience yield. According to eq. (24), the market is in normal contango whenever wealth and production move in opposite directions or are weakly related.[5] On the other hand, normal backwardation is likely to arise when such linear relationship is sufficiently strong. At the other extreme, suppose firms only were active on the permits market. In this case eq. (22) rewrites

$$F^*(\lambda = 1) = E(p_2^*) \left[1 + \tau^{-1} cov(\Delta E_2, p_2^*)\right], \tag{25}$$

and the convenience yield is determined by the comovement between firms' and aggregate permits shortage. Note that eq. (25) prescribes that the market is always in normal contango since with only firms we have

$$cov(\Delta E_2, p_2^*) = CV(p_2^*),$$

so that more volatile date 2 prices will require a higher risk premium.

The futures equilibrium price in eq. (22) can be equivalently written as

$$F^* - E(p_2^*) = \tau^{-1} \left[CE(p_2^*) V(p_2^*) - C^{-1} \beta \eta \sigma_{W,Y}\right], \tag{26}$$

The latter equation highlights how a environmental policy affects the convenience yield. Suppose $\sigma_{W,Y} < 0$ so that the market is in normal contango, i.e. $F^* > E(p_2^*)$. Then a tight environmental policy and/or uncertainty about future permits supply would make permits prices more volatile, and the convenience yield widens.

[5] Assumption A.5 gives $cov(w_j, Y_2) = \eta \sigma_{W,Y}$, so that financial wealth is correlated with date 2 permits prices from eqs. (11) and (6).

3 Empirical analysis

3.1 Econometric specification

We first need to find an empirical counterpart to eq. (26). To simplify matters, we are going to assume that: 1) all firms are identical in terms of their marginal costs, i.e. $c_i = c$ for all i and 2) all firms participate are subject to the cap-and-trade mechanism, so that $\beta = 1$ and 3) all speculators are active in the permits market. These assumptions imply, respectively, that $C = \lambda/c$, $\beta = 1$ and $\eta = 1$.

We first find a closed form for the expected date 2 permits price, conditional on date 1 information. As we show in the appendix, we have that:

$$E\left(p_2^*\right) = p_1^* + \frac{c}{\lambda}\left(\bar{E}_1 - \mu\right) \tag{27}$$

So that eq. (26) rewrites as

$$F^* - \underbrace{\left[p_1^* + \frac{c}{\lambda}\left(\bar{E}_1 - \mu\right)\right]}_{=E\left(p_2^*\right)} = \tau^{-1}\left[\underbrace{\left[\frac{\lambda}{c}p_1^* + \left(\bar{E}_1 - \mu\right)\right]}_{=\frac{\lambda}{c}E\left(p_2^*\right)} V\left(p_2^*\right) - \frac{c}{\lambda}\sigma_{W,Y}\right] \tag{28}$$

and substituting for $V\left(p_2^*\right)$ [see eq. (13)] we have:

$$F^* - \left[p_1^* + \frac{c}{\lambda}\left(\bar{E}_1 - \mu\right)\right] = \frac{c}{\lambda\tau}\left(\left[p_1^* + \frac{c}{\lambda}\left(\bar{E}_1 - \mu\right)\right]\left(\sigma_Y^2 + \lambda\sigma_\varepsilon^2 + \sigma^2 - 2\sigma_{E,Y}\right) - \sigma_{W,Y}\right) \tag{29}$$

From eq. (29) we can see how the different variables make (normal) contango, $F^* > E\left(p_2^*\right)$, or (normal) backwardation, $F^* < E\left(p_2^*\right)$, more likely, as follows. Suppose that $\bar{E}_1 - \mu > 0$, so that $E\left(p_2^*\right) > 0$ from eq. (27). Then contango is more likely whenever: 1) the marginal cost, c and/or 2) current spot prices, p_1^*, are high, while backwardation is more likely whenever $\sigma_{W,Y}$ is high. Finally, high uncertainty about future spot prices (as captured by $\sigma_Y^2 + \lambda\sigma_\varepsilon^2 + \sigma^2 - 2\sigma_{E,Y}$) leads to contango as well. Note that a tight environmental policy, i.e. $\sigma_{E,Y} < 0$, increases volatility of future permit prices, and as a result widens the gap between futures and current permit prices.

Before proceeding, it is convenient to rewrite eq. (29) as

$$F^* - p_1^* = \frac{c}{\lambda}\left(\bar{E}_1 - \mu\right) + \frac{c^2}{\lambda^2\tau}\left(\bar{E}_1 - \mu\right)\hat{V}\left(p_2^*\right) + \frac{c}{\lambda\tau}p_1^*\hat{V}\left(p_2^*\right) - \frac{c}{\lambda\tau}\sigma_{W,Y} \tag{30}$$

where we set $\hat{V}(p_2^*) = \sigma_Y^2 + \lambda\sigma_\varepsilon^2 + \sigma^2 - 2\sigma_{E,Y}$. To test the validity of equation (30) we first need to find empirical counterparts to the RHS variables. Our ultimate goal is to "extract" the market expectations about future environmental policy from eq. (30) –specifically the future supply of permits, μ, as well as the environmental policy tightness $\sigma_{E,Y}$.

3.2 Data and results

We use daily data for the EU ETS Phase I (2005-2007) between June 24, 2005 and December 28, 2007 to infer expectations about Phase II environmental commitment.

EUA prices. EUA quotes are gathered from Powernext Carbon and the European Climate Exchange (ECX), the most liquid markets for spot and futures transactions, respectively. Spot and futures prices are expressed in €/ton of CO_2 up to two decimal points. Futures contracts have expiries in December, on the last Monday of the contract month. We collect daily quotes for the five contracts with delivery during Phase II, i.e. December 2008, 2009,. 2010, 2011 and 2012.

Abatement cost. As a proxy of the abatement cost, c, we follow Alberola, Chevallier and Chèze [3] and construct the switch price of CO_2 (coal/gas in €/MWh) as[6]

$$s = \frac{\text{cost(gas)/MWh} - \text{cost(coal)/MWh}}{\text{tCO}_2\text{(coal)/MWh} - \text{tCO}_2\text{(gas)/MWh}}$$

where cost(gas)/MWh (resp. cost(coal)/MWh) is the production cost of one MWh of electricity on base of net CO_2 emissions of gas (resp. coal) in €/MWh, while tCO_2(coal)/MWh (resp. tCO_2(gas)/MWh) is the emissions factor in CO_2/MWh of a coal-fired (resp. gas-fired) plant. We use the day ahead price series for NBP and CIF ARA to measure the electricity production costs of gas and coal, respectively.[7]

[6] As calculated by the Caisse des Dêpóts-Climate Task Force for Tendances Carbone (the methodology is available on the website http://www.caissedesdepots.fr/actualite/mediatheque/recherche-climat/finances-carbone.html, accessed on June 2009).

[7] Gas NBP day ahead data are quoted from Bloomberg in pence/therm. The conversion rate from pence/therm to £/Mwh is (1/0,0293)*(1/100) (Argus coal daily international); historical exchange rates £/euro (WM Reuters) are used to obtain the series in euro/Mwh. API 2 CIF ARA is a daily assessment from Platts in \$/ton. We use a conversion rate from \$/ton to \$/Mwh equal to 1/6,9767 (Argus coal daily international); historical exchange rates \$/euro (WM Reuters) allows to obtain the series in euro/Mwh. Average productive efficiency is assumed at 50% for gas plants and 36% for coal plants (see www.carbonomics.com/ipcc).

Finally, we set emission factors to $0.86 tCO_2/MWh$ and $0.36 tCO_2/MWh$ for gas-fired and coal-fired plants, respectively.

Financial wealth. From DATASTREAM we retrieve daily values for the Dow Jones STOXX 600 index (total return), which includes 600 large, mid and small capitalization companies across 18 countries of the European region. As a proxy for the covariance between financial wealth and production, $\sigma_{W,Y}$, we use the daily realized covariance between the stock market and the EU allowance market.

As a preliminary check, we run standard unit root tests on all price series (spot and futures EU allowances as well as coal and gas), and find compelling evidence that they are non-stationary. Moreover, convenience yields are $I(1)$ as well. Thus, we follow Helfand, Moore and Liu [11] and Alberola, Chevallier and Chèze [3] and compute one-step ahead forecast errors for all price series. Specifically, we consider 30 observations from June 25, 2005 to August 8, 2005 and estimate an OLS regression including a time trend and five trading-day dummies for each series. The estimated coefficients are then used to produce the forecast of each price series on August 9, 2005.

Finally, we compute for each series the forecast error as the difference between the actual price on August 9, 2005 and the forecast value. This process is then repeated every day rolling-over the thirty-day estimation window. Overall, we generate 593 one-day ahead errors for each price series (from August 9, 2005 to December 28, 2007) which we use to compute: 1) convenience yields, $(F_i - p)_t$, for each future contract i 2) switch CO_2 prices, s_t, and 3) realized covariances between the Dow Jones STOXX 600[8] and the EUA spot market, Σ_t –defined as the product between daily Dow Jones STOXX 600 log-returns and daily EUA spot log-returns– which we use as a proxy for the covariance between financial wealth and production, $\sigma_{W,Y}$.

Thus, for each futures series, we establish the following regression

$$(F_i - p)_t = \delta_{i,1} + \delta_{i,2} s_t + \delta_{i,3} s_t^2 + \delta_{i,4} p_t s_t + \delta_{i,5} s_t \Sigma_t + \varepsilon_{i,t} \tag{31}$$

[8] We don't apply the one-step ahead procedure to the stock market price series, as it enters our econometric specification via daily log-returns, which are stationary.

as the empirical counterpart to the pricing equation (30). We expect:

$$\delta_{i,4} \geq 0$$

$$\delta_{i,5} \leq 0$$

Importantly, $\delta_{i,2}$ measures the expectation about future allowances supply with $\delta_{i,2} > 0$ corresponding to fewer permits issued during Phase II.

We estimate the model (31) for the five futures contracts deliveries with OLS regressions for the entire sample as well as selected subsamples. Standard errors are corrected using the Newey-West method.

In our empirical analysis we follow the existing literature (see, among others, Alberola, Chevallier and Chèze [3]) and allow for the existence of a break in 2006. On April 24, 2006, spot prices dropped due to the first "compliance check", showing that verified emissions were lower than the amount of allowances distributed to firms during 2005. In October 2006, the EC announced stricter supply of permits for Phase II. We therefore separately study the two sub-periods, looking for evidence that may confirm that participants in the markets changed their view about the long run supply.

Table 1 reports results before the break, for sample between August 9, 2005 and April 24, 2006. For each sample and futures delivery we report coefficient estimates as well as their t-statistics (rows 1 to 5). The coefficient δ_4 is positive, but not significantly so, and δ_5 is significantly negative, as expected. δ_2 is significantly negative.

	DEC 08	DEC 09	DEC 10	DEC 11	DEC 12
δ_2	-0.0090***	-0.0092***	-0.0095***	-0.0098***	-0.0101***
	(-2.909)	(-3.035)	(-3.224)	(-3.453)	(-3.520)
δ_3	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
	(3.066)	(3.291)	(3.232)	(3.205)	(3.054)
δ_4	0.0056	0.0058	0.0056	0.0054	0.0055
	(1.116)	(1.165)	(1.151)	(1.108)	(1.076)
δ_5	-29.7205**	-30.8501**	-31.9302**	-32.3368**	-32.4492**
	(-2.240)	(-2.318)	(-2.385)	(-2.398)	(-2.326)
δ_1	-0.0387	-0.0449	-0.0417	-0.0376	-0.0328
	(-0.175)	(-0.200)	(-0.186)	(-0.166)	(-0.144)
Adj. R^2	0.102	0.105	0.109	0.111	0.111
F-stat	5.907	6.078	6.272	6.393	6.413
Prob(F-stat)	0.000	0.000	0.000	0.000	0.000
Obs	174	174	174	174	174

TABLE 1: BEFORE THE BREAK. Regression results for eq. (31) over the period August 9, 2005 to April 24, 2006.

Table 2 reports results for the period after the break. The estimated coefficients are usually not significantly different from zero, except for that associated with the expected change in supply, which is negative for the long maturities to 2011 and 2012.

	DEC 08	DEC 09	DEC 10	DEC 11	DEC 12
δ_2	-0.0127	-0.0131	-0.0135	-0.0138*	-0.0142*
	(-1.602)	(-1.596)	(-1.635)	(-1.691)	(-1.750)
δ_3	0.0003	0.0003	0.0003	0.0003	0.0003
	(0.609)	(0.692)	(0.671)	(0.666)	(0.665)
δ_4	-0.0113	-0.0125	-0.0126	-0.0128	-0.0127
	(-1.281)	(-1.338)	(-1.342)	(-1.356)	(-1.362)
δ_5	-12.9329	-16.0594	-15.7187	-15.8138	-15.0325
	(-0.959)	(-1.127)	(-1.090)	(-1.095)	(-1.033)
δ_1	0.0619	0.0580	0.0568	0.0547	0.0520
	(0.625)	(0.589)	(0.576)	(0.553)	(0.522)
Adj. R^2	0.045	0.053	0.055	0.057	0.058
F-stat	3.486	3.962	4.067	4.196	4.269
Prob(F-stat)	0.009	0.004	0.003	0.003	0.002
Obs	212	212	212	212	212

TABLE 2: AFTER THE BREAK. Regression results for eq. (31) over the period June 26, 2006 to April 30, 2007.

Overall, the estimation results thus show that both compliance and non compliance agents do believe in the announcements of governments about future supply. Markets were expecting more permits to be issued in Phase II, widening the convenience yield. This result echoes some related findings analyzed in Alberola, Chevallier and Chèze ([2]) who conclude that uncertainty about future supply has been a significant driver of the EUAs spot price during 2005, but not 2006. Our model, however, differs from

Alberola, Chevallier and Chèze ([2]) in that they measure political uncertainty by an ad-hoc proxy[9], while we capture expectations incorporated in the future-spot price differential.

4 Conclusions

We interpret the price of emission permits on the basis of a model with firms and financial speculators. Trading activity takes place on both spot and futures markets. We assume that banking (spot) permits across dates is not allowed, consistently with the interphase rule applied within the EU ETS. Each firm emits pollutants at both dates, and emissions are subject to regulation via a trading mechanism. Firms may abate emissions through a costly technology. Speculators' utility is affected by exogenous wealth shocks and actions in the spot-futures market. There are three sources of economic uncertainty: business-as-usual emissions, allowance endowments and financial wealth.

We derive an equation where the convenience yield depends on the switching cost, the square of the switching cost, the product between the switch and the correlation between the spot price and the stock market, the product between the switch and the spot price. Our results are consistent with the market modifying the long run expectations of supply during Phase I. Announcements on the part of the EC about a future reduction in supply were successful, regardless of the empirical evidence showing an excess current supply of permits.

The economic interpretation emerging from our results is interesting. The commitment to create a market for trading emission permits on the part of the EU was credible. This was not obvious ex-ante due to lack of international coordination, with important players like the US, Australia and emerging countries deciding not to sign the Kyoto Protocol. The unilateral effort on the part of a block of countries to go ahead with an allowance market could have been destroyed by mistakes in determining supply. On the contrary, the EU was able to reaffirm its commitment, even after empirical evidence

[9] 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.

showed the existence of a large oversupply of permits in Phase I. Investors however regarded that as a sort of unavoidable cost associated with learning the position of the permits demand curve.

At the time of this writing, other countries, e.g. the US and Australia, are evaluating the possibility of setting up a market for emission trading. Spence [20] evaluates the possibility of a world market for emission permits, initially limited to developed economies. The EU experience may be very useful to both governments and investors. Governments in other blocks may interpret the EU experience as a signal about the importance of correctly estimating the demand function to avoid unnecessary market volatility. Investors may use the existing empirical evidence as a signal that governments themselves move in conditions of uncertainty when setting the supply of permits. The resulting short-term volatility may well justify a substantial premium to enter the market, particularly at early stages.

5 Appendix

We first establish and prove the following:

Lemma 2 *Let the vector* (X,Y) *follow a bivariate normal distribution. Then*

$$cov\left(XY,X\right)=E\left(Y\right)V\left(X\right)+E\left(X\right)cov\left(X,Y\right) \tag{32}$$

Proof. By the definition of covariance, we have that

$$cov\left(XY,X\right)=E\left(X^2Y\right)-E\left(XY\right)E\left(X\right)=E\left(X^2Y\right)-\left[cov\left(X,Y\right)E\left(X\right)+E\left(Y\right)E^2\left(X\right)\right]. \tag{33}$$

Suppose further that (X,Y) is bivariate normal. Then we know that all odd centered moments are nil, so that

$$E\left[\left(X-E\left(X\right)\right)^2\left(Y-E\left(Y\right)\right)\right]=0.$$

Expanding terms on the LHS and rearranging gives us

$$E\left(X^2Y\right)=E\left(Y\right)\left(V\left(X\right)+E^2\left(X\right)\right)+2E\left(X\right)cov\left(X,Y\right).$$

Using the latter into eq. (33) and rearranging yields eq. (32). □

Proof of Proposition 1. The futures equilibrium price satisfies the market clearing condition

$$\textstyle\int_0^\lambda f_i^* di+\int_\lambda^1 f_j^* di=0,$$

which by means of eqs. (21) and (15) rewrites as

$$F^*=E\left(p_2^*\right)+\tau^{-1}\left\{-\frac{C}{2}cov\left[\left(p_2^*\right)^2,p_2^*\right]+\textstyle\int_0^\lambda cov\left(p_2^*\Delta e_{i2},p_2^*\right)di-\int_\lambda^1 cov\left(w_j,p_2^*\right)dj\right\} \tag{34}$$

where τ is the market risk tolerance defined in eq. (23). Straightforward application of eq. (32) in Lemma 1 gives

$$cov\left(\Delta e_{i,2}p_2,p_2\right)=E\left(\Delta e_{i,2}\right)V\left(p_2\right)+E\left(p_2\right)cov\left(\Delta e_{i,2},p_2\right), \tag{35}$$

and

$$cov\left[\left(p_2^*\right)^2,p_2\right]=2E\left(p_2^*\right)V\left(p_2^*\right). \tag{36}$$

By means of eqs. (36) and (35) we rewrite eq. (34) as

$$F^* = E(p_2^*) + \tau^{-1}\left[-CE(p_2^*)V(p_2^*) + E(\Delta E_2)V(p_2^*) + E(p_2^*)\int_0^\lambda cov(\Delta e_{i2}, p_2^*)\,di - \int_\lambda^1 cov(w_j, p_2^*)\,dj\right]$$

Since $E(\Delta E_2) = CE(p_2^*)$ by eq. (11), $-CE(p_2^*)V(p_2^*) + E(\Delta E_2)V(p_2^*) = 0$ so that the future prices reads as

$$F^* = E(p_2^*) + \tau^{-1}\left[E(p_2^*)\int_0^\lambda cov(\Delta e_{i,2}, p_2^*)\,di - \int_\lambda^1 cov(w_j, p_2^*)\,dj\right]$$

which is eq. (22).

Derivation of eq. (27). Eqs. (4) and (6) allow us to write

$$\Delta E_2 = Y_1 + \varepsilon + \int_0^\lambda \varepsilon_{i2} di - \bar{E}_2,$$

while for date 1 we have

$$\Delta E_1 = Y_1 - \bar{E}_1.$$

Using the latter in the former yields the following recursion on the aggregate permits shortage

$$\Delta E_2 = \Delta E_1 + \bar{E}_1 + \varepsilon + \int_0^\lambda \varepsilon_{i2} di - \bar{E}_2,$$

and taking expectations, we rewrite the date 2 price as

$$E(p_2^*) = \frac{c}{\lambda}\left(\Delta E_1 + \bar{E}_1 - \mu\right).$$

Finally, since $p_1^* = \frac{c}{\lambda}\Delta E_1$, then eq. (27) follows.

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