Impact of the Allowance Allocation on Prices and Efficiency

Karsten Neuhoff, Michael Grubb and Kim Keats

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Karsten Neuhoff[1], Michael Grubb[2], Kim Keats[3]

The EU CO_2 emissions trading scheme was inspired by successful cap and trade programs for SO_2 and NO_x in the US. Most US programs allocated allowances to large emitters based on a historic base line for a period of up to thirty years. The National Allocation Plans in Europe deviate from this principle and allocates allowances in an iterative approach first for a three then for a five-year period. The potential updating of the base line creates perverse incentives for operation and investment. Most National Allocation Plans also reserve allowances for new entrants further distorting the scheme. We use analytic models and a numeric simulation for the UK power sector to illustrate and quantify how these effects contribute to an inflation of the allowance price while reducing utilisation and investment in efficient technologies. The inflated allowance prices are likely to increase the European allowance budget and emissions, e.g. through the Linking Directive. As a result opportunity costs of emitting CO_2 are reduced relative to an efficient cap and trade program.

1. Introduction

The European Emissions Trading Scheme (EU Directive 2003/87/EC) aims to control CO_2 emissions from power generation and heavy industry in the context of countries' Kyoto Protocol targets. It started operating on 1st January 2005. This is based on the cap-and-trade model following successful experience with similar programmes for SO_2 and NO_x emissions in the US (Ellerman et. al. 2000). The annual market value of the total allowances issued at current trading prices (June 2005) is €40bn, making it by far the world's largest environmental management programme. Emission allowances are allocated to installations in the power, ceramics, metal, paper and cement industries and any other large combustion plant with a rated thermal capacity above 20MW, comprising in total about half of EU CO_2 emissions, of which two-thirds is from power generation. Installations can trade these allowances but at the end of each year must hold enough allowances to cover each (metric) tonne of carbon dioxide (tCO_2) emitted.

[1] Cambridge University, Karsten.Neuhoff@econ.cam.ac.uk

[2] Imperial College, Cambridge University and Carbon Trust, michael.grubb@thecarbontrust.co.uk

[3] ICF Consulting, KKeats@icfconsulting.com

EU Member States are required to allocate emission allowances to participating facilities in sequential periods. The first phase, 2005-07, is precursor to the second, which coincides with the Kyoto Protocol's First Commitment Period (CP1) of 2008-12. National governments have retained some allowances, which will be either allocated to new entrants or auctioned to market participants. Member States are allowed to auction up to 5% and 10% of the total allowances issued respectively in the first two periods; the rest must be allocated for free. The final allocation plans for the first period were agreed with the European Commission in spring 2005. Allocation plans for the Kyoto period are due to be agreed for the Kyoto period during 2006.

While member states are obliged to adhere to the allocation plans they submitted to the commission, the total amount of national emissions for the present period are not legally constrained: EU Member States are meant to be on a pathway towards achieving the agreed Kyoto emission reductions for 2008-12. Member States retain discretion over how many of their emission reductions they expect to achieve in the sectors covered by the EU ETS, as compared to the remaining sectors - mainly transport and heating – and by use of the Kyoto international mechanisms.

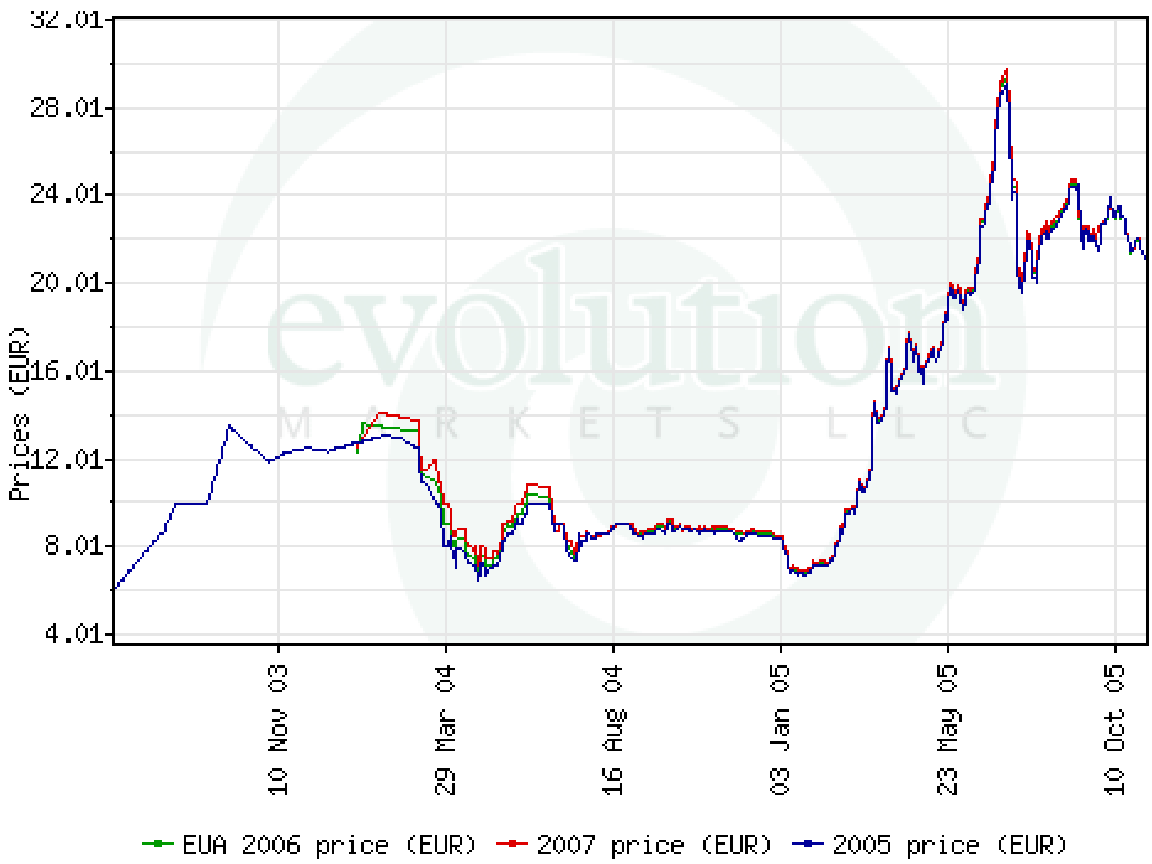


Figure 1 Price at which emission allowances were traded in forward markets, Source: Evolution Markets.

A forward market for EU Allowances has been developing. Figure 1 illustrates the price at which the forward markets priced allowances for the period 2005-2007. Prices have changed significantly, reflecting changes in market expectations of total allowances allocated to the covered sectors. At recent trading prices exceeding €20/tCO2, the annual market value of the allowances exceeds €40bn.

In principle, once allocations are known and fixed, subsequent trading should result in efficient abatement decisions that minimise the costs of meeting the Kyoto greenhouse gas (GHG) emissions reduction targets. Indeed in some respects, the EU ETS is close to an economist's ideal structure for internalising a market externality with minimal competitive impacts. In other respects, however, it differs significantly from this ideal. The combination of large free allocations, flexibility over the allocation methodology, and separate negotiations for each five-year period, create risks of a substantial divergence from theoretical efficiency as well as room for dispute and distortion between different participants. This paper sets out the analytic fundamentals of how the real-world economics of the EU ETS may differ from the economists' ideal, with particular reference to the power sector.

In practice, electricity market structures in different EU countries vary considerably, and each country has leeway in defining how they allocate allowances to their industries. Both market and allocation realities differ from the theoretical ideal in several respects. We survey briefly how market structures may affect the pricing implications of the EU ETS and then focus on three allocation issues:

- First, it is likely that today's emissions could influence allocation of CO_2 allowance in some future period. We will refer to this process as 'updating' of the base line that determines the allowance allocation.
- Second, in many of the national allocation plans (NAPs) new entrants will be awarded allowances from a new entrant reserve, reducing the cost of new entry.
- Third, the allocation to existing units in some countries is subject to minimum operating conditions, which encourages them to remain online thereby reducing the scarcity value of capacity.

We use analytic models to assess the impact of these three issues in two-period and multi-period models for operation and investment. We obtain two robust results which we then quantify using an investment planning model. First, relative to an efficient allocation based on historic output or auctions, the updating mechanism inflates allowance prices. Secondly, if Linking Directive or other mechanisms increase the number of allowances in the system at higher allowance prices, then the opportunity cost of emitting CO2 is reduced relative to an efficient allocation using auctions or grand-fathering.

In section 2 we introduce the economics of allowances in the power sector. Section 3 analyses in the static case the impact of different allocation mechanisms on allowance price, emissions and power prices. Section 4 moves to the dynamic case assessing the impact on investment decisions of updating and new entrant allocation. The analytic results are summarised in section 5. Section 6 provides numerical results for the various cases at the example of the UK power sector assuming a fixed allowance price. Section 7 discusses why the amount of allowances in the European system can be a function of allowance price in contrast to the US situation with fixed caps[4] and finally section 8 concludes.

2. The Economics of the EU ETS for the power sector: an overview

Rent value of allocation and cost pass-through

Toman et.al. (1998) show that under a scheme in which the baseline reference period remains unchanged (grandfathering), the scarcity rent of CO2 allowances is passed onto owners of generation assets. Grandfathering emission certificates requires extensive information about past emissions and political negotiations on a number of issues including the treatment of new entrants (Harrison and Radov, 2002) and the split between different sectors (Sijm et. al.,2002). Bode (2004) assesses the impacts of additional options for the design of national allocation plans – like using benchmark emission rates. Crampton and Kerr (2002) conclude that an auctioning of emissions certificates would avoid these problems. The state government could use auction revenue to decrease distortionary taxes, compensate those sectors or consumers most impacted by price increase, or recycle the funds to other types of energy efficiency projects (Barker et. al. 1993, Zhang and Baranzini 2003).

General equilibrium models show that the macroeconomic costs of the CO_2 control program are significantly higher under grandfathering than when all allowances are auctioned and recycled through marginal personal income tax rate cuts (Smith and Ross, 2002). Burtraw et.al. (2002) applied an investment planning model to the US electricity system and calculated that only 20.5% of allowances would have to be allocated for free to compensate generators for their increased costs – the remaining cost increase would be covered by an increase in wholesale prices. The remaining allowances could be allocated in an auction. However, it seems that the fraction of grandfathered allocations is determined in a political bargaining process (Bovenberg et. al 2003) to obtain the support for the scheme of the generation sector.

Impact of CO_2 opportunity costs on electricity prices

Electricity demand changes over the day and year. Generation plants with high fixed costs and relatively low operating marginal costs, such as nuclear and run-of-river hydro, generate throughout the year. Units with lower fixed costs but higher operating marginal costs are used to provide electricity during shoulder and peak demand periods.

Of particular interest for our study are pulverised coal-fired plants (PC) and natural gas-fired combined cycle gas turbine plants (CCGT). Variable costs of both plants are determined mainly by their marginal fuel costs. At present (June 2005), PC plants operate for more hours per year than

[4] Even the US SO_2 cap offered limited flexibility. In phase I some facilities could decide on a year by year basis whether they wanted to be covered by the emission trading scheme (opt in) or be exposed to traditional regulation. Only facilities that expected to require less allowances than allocated when opting in would do so. This has provided approximately 2-3% extra allowances to the remaining facilities (Ellerman, 2003).

CCGTs. However, the investment cost for new PC plants is almost twice that for CCGT. Moreover, permitting processes tend to be more difficult for PC plant due to their larger environmental impact. As a result, most of the new power stations constructed over the past decade in Europe have been gas-fired CCGT.

Now the introduction of CO_2 allowances will play a crucial role in determining the relative cost of these technologies. The CO_2 emissions per MWh of electricity produced by a modern coal plant are more than twice as high as from combined cycle gas turbines, so a CO_2 constraint increases PC's costs more than CCGTs.

In the short-term, electricity prices are set by the marginal unit. The marginal units tend to be those consuming fossil fuels, and as such are always exposed to CO_2 allowance prices. Therefore, the price of electricity can be expected to rise in all periods. However, if the marginal unit emits more CO_2 than an average unit then the electricity prices increase by the opportunity costs of CO_2 emissions of the marginal unit which are above the average costs of CO_2 allowances for the generation sector. In two cases this might not apply. First, if gas prices are high and gas-fired units set the price, then the electricity price will increase by the cost of CO_2 allowances for gas-fired units which would be half the increase in cost for PC units. Second, if increases in electricity prices elicit a compensating demand response, then prices will also rise by less than the opportunity costs of the marginal unit. The latter is unlikely to be significant since electricity demand tends to be inelastic.

The weight of these individual effects differs depending on fuel prices and generation mix. Burtraw calculates that for the US, 20.5% of allowances need to be allocated for free to ensure that firms will not incur losses due to the introduction of emission trading (2003) and similar numbers result from various studies for the ETS *(Dinan, 2003, ILEX 2003, OXERA 2004, Keats and Neuhoff 2004)*.

Figure 2 shows results for a UK simulation assuming a fixed generation structure and cost factors as described in more detail in section 6. CO_2 allowances increase the electricity cost for consumers (revenue for generators) independent of whether allowances are auctioned or grandfathered based on a historic base line.

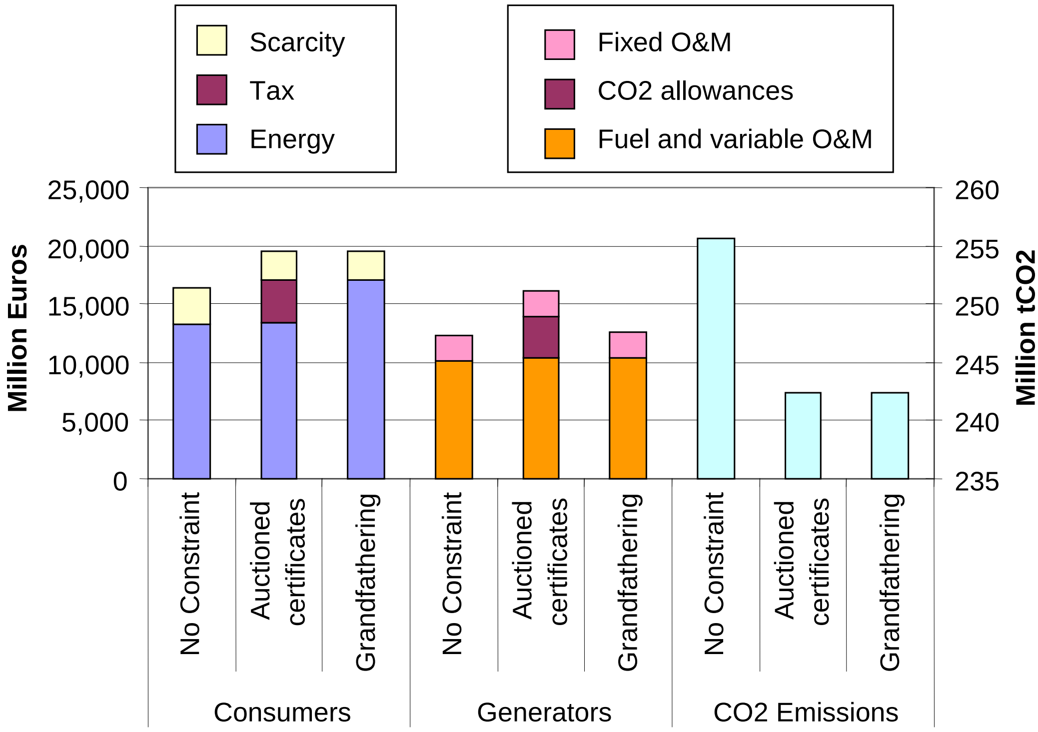


Figure 2 UK simulation results (2005-2007)

The increased revenue roughly compensates the generation sector for the cost it would incur if CO_2 allowances were auctioned, but creates a windfall profit for generators if allowances are grandfathered. The CO_2 emissions reductions are independent of the allocation mechanism.

This analysis assumes a competitive market. If we assume that generators have market power in the wholesale market then they are likely to continue to pass through at least some of the opportunity costs. In a Cournot model the assumptions about demand determine whether strategic generators increase electricity prices by more or less than the increase in opportunity costs.[5] Note that, if vertical integration persists and retail prices of the incumbent are regulated, then the regulator might not allow the full pass through of the opportunity cost of CO_2.

3. Static analysis of updating and banking, without investment

In this section we formalise the main issues in evaluating the impacts and incentives associated with the EU ETS.

[5] With linear demand, an increase in the opportunity cost decreases total demand and therefore the incentive to withhold output. Linear Cournot models suggest that strategic generators can only pass through part of any cost increase. In contrast, if we assume constant demand elasticity, then the oligopoly price will increase by more than the increase of opportunity costs. This can be shown as follows:
Assume n generators, demand elasticity ε, marginal cost c and price P that $\varepsilon/n=1-c/P$. With a 10% increase of marginal costs c the price also has to increase by 10%, and therefore by more than marginal costs. Therefore constant demand elasticity implies an opportunity cost pass through of more than 100%.

We assume emissions $E(c)$ to be a decreasing function in opportunity costs c of emitting CO_2:[6] $E(c)' < 0$.

With updating, the opportunity costs c_t of emitting CO_2 is equal to the costs of allowances p_t minus the value of free future allocation p_{t+1}. For each unit of CO_2 emissions today, assume that a firm receives only a fraction u of CO_2 allowances in the next period. The price of future allowances is discounted by the factor β:

$$c_t = p_t - u\beta p_{t+1} \qquad (1)$$

$A(),A'\geq 0$	Allowances provided to market	p_t	Allowance price in period t
$E(),E'<0$	Emissions at opportunity costs c	c_t	Opportunity costs of emitting in t
u	Updating: fraction of emission in t allocated for free in t+1	β	Discount factor β=1/(1+r)
$p_{elec,t}$	Electricity price in t	λ	Emissions/unit electricity
M	Free allowances allocated to new entrant	$D(p_{elec})$	Electricity demand at price p_{elec}
c_f	Fixed (investment) costs for entry	μ	Number of allowances for the new entrants
K_i	Installed capacity of type i	$c_{m,i}$	Marginal cost for type i

Table 1 Symbols used in analysis

3.1 Introduction of updating together with trading

Prior to 2005, there was no constraint on CO_2 emissions (p_t=0) but it could have been possible that emission levels in 2004 would have influenced the allowance allocation for the first Kyoto commitment period (2008-2012). Any expectation that increased 2004 emissions would result in increased allocation (updating, u>0) creates a negative opportunity cost of emitting CO_2 (c_t<0). For illustration, if companies in 2004 assumed that an updating factor of $u=0.7$ would be applied with 0.5 probability, with a discount factor of $\beta=0.9$ over 5 years and expect a CO_2 allowance price of 20€/tCO_2 for 2008, then the opportunity costs of emitting CO_2 in 2004 were

$$c_{2004} = p_{2004} - u*\beta*p_{2008} = 0 - 0.5*0.7*0.9^5 * 20€/t = -4.1€/t \qquad (2)$$

[6] In a competitive market, firms set output such that price equals marginal production costs. Demand decreases with increasing production costs and firms might operate less carbon intensive technologies when opportunity costs of CO2 emissions are higher.

Under these assumptions, the opportunity costs of emitting CO2 in 2004 would have been negative 4.1€/tCO_2. This could have created incentives to shift production towards units with higher CO_2 intensity and also resulted in lower wholesale electricity prices.

3.2 Updating within an existing trading scheme

To simplify the presentation, we make the initial assumption that banking is not allowed. If a CO_2 trading mechanism is already in place, then total emissions *E* may not exceed the number of issued allowances A≥E. We assume positive allowance prices and therefore that the constraint is binding:

$$A(p_t) = E(c_t) = E(p_t - u\beta p_{t+1}) . \qquad (3)$$

The impact of updating can be seen by assessing how the equilibrium changes with a change in *u*. Differentiating with respect to *u* gives (Note, we define $A' = \frac{\partial A}{\partial p_t}$ $E' = \frac{\partial E}{\partial c_t}$):

$$\frac{\partial p_t}{\partial u} = \frac{\beta p_{t+1} + u\beta \frac{\partial p_{t+1}}{\partial u}}{1 - A'/E'} \geq 0 \qquad (4)$$

Increasing the updating factor increases the allowance price by the value of future allowance allocation (weakly) and may also increase the value of future allowance allocation from future updating. This effect is mitigated if an increased allowance price results in an increase of the total amount of allowances in the market A'>0 because E'<0.

Initially, we assume the total allowed emissions to be fixed (A'=0). Then we explore the implications if the A depends on the allowance price. This can happen where flexible mechanisms allow for inflow of allowances from outside the EU ETS or from the influence of CO_2 allowance prices on political negotiations of emission targets. To facilitate this, we retain A' in the following formulae.

Electricity prices are directly dependent on the opportunity costs of emitting CO_2 allowances and the qualitative impact of updating on electricity prices can be approximated by the opportunity costs of emitting CO_2. Differentiating (1) with respect to u and then substituting p'_t from (4) gives:

$$\frac{dc_t}{du} = p'_t - \beta p_{t+1} - u\beta p'_{t+1} = A'/E' \frac{\beta p_{t+1} + u\beta p'_{t+1}}{1 - A'/E'} \qquad (5)$$

If we assume a one-off updating (e.g. subsequently allowances are expected to be auctioned) and no banking then future allowances prices are not affected (p'_{t+1}=0). In this case (5) implies that dc_t/du<=0. While current allowance prices increased with a one-off updating (4), the opportunity cost of emitting CO_2 is not affected for A'=0 (5). Only if A'>0 and the total amount of allowances available within the country increases with allowance prices, can the opportunity cost c_t of emitting CO_2 decrease with updating (in (5) $A' \geq 0$, $E<0$, $p_{t+1}'=0$). In this case electricity prices, which in a competitive electricity market also reflect the opportunity cost of allowances, increase by less than in an efficient scheme without updating. With $A'>0$, one-off updating results in a reduction in the electricity price pass through of allowance prices.

The impact of allowance prices on the total quantity of emissions depends on the elasticity of total supply:

$$\frac{\partial E}{\partial u} = E' \frac{\partial c_t}{\partial u} = A' \frac{\beta p_{t+1} + u\beta p'_{t+1}}{1 - A'/E'}. \qquad (6)$$

In general, the impact of updating on total emissions is increasing with elasticity of allowance supply A' (with zero impact at A'=0) and decreasing with the response of production of CO_2 to opportunity costs of emitting E'. Assuming linear responses and no updating in future periods ($p'_{t+1}=0$) this would imply that total emissions are increased by:

$$dE = \frac{A'}{1 - A'/E'} \beta p_{t+1} u. \qquad (7)$$

If **updating is applied beyond the first commitment period**, then in an extreme scenario we could assume that it will continue to be applied over allocation periods of 4-5 years. In this case updating will not only reduce today's electricity price but also future electricity prices.

Assume increasing allowance prices – e.g. due to increasing political awareness or intertemporal arbitrage – and for simplicity assume the rate of price increase follows the discount rate of generators ($p_t = \beta p_{t+1}$). Equation (4) turns into:

$$\frac{\partial p_t}{\partial u} = \frac{p_t}{1 - u - A'/E'}. \qquad (8)$$

In linear approximation of A and E (8) can be given as:

$$p_t(u) = p_t(u=0)(1 - A'/E')/(1 - u - A'/E') \qquad (9)$$

In the extreme case with fixed allowance price, A'->inf. (9) confirms a constant price. In the other extreme, with fixed allowance budget, A'=0, updating increases the allowance price by 1/(1-u).

Substituting into (1) shows (using a first order approximation in u)

$$c_t = p_t - u\beta p_{t+1} = p(0)(1-u)\frac{1 - A'/E'}{1 - u - A'/E'}$$

Looking again at the extreme case of fixed allowance price (A'->inf.) gives $c_t(t)=p_t(0)(1-u)$. Updating reduces opportunity costs of emitting CO_2 and A'>0 results in additional supply of allowances.

In contrast, if A'=0 then $c_t(t)=p_t(0)$. While allowance prices are inflated with updating, the opportunity costs of emitting are not affected because the increased prices of today's allowances are exactly compensated by the increased value of higher priced future allowances received through the updating mechanism. This result is restricted to an economy with one sector, because distortions will occur if various sectors or regions can trade allowances, but are exposed to different updating mechanisms.

For $A' > 0$, (6) becomes:

$$\frac{\partial E}{\partial u} = A' \frac{\beta p_{t+1}}{1 - u\beta - A'/E'}. \qquad (10)$$

Comparing (6) and (10) shows, that continuous updating enhances the impact on emissions as the denominator is reduced by uβ. The discount factor β relates to discounting between different allocation periods and is therefore significantly smaller than 1. Furthermore, u also involves consideration of policy uncertainty, in particular whether updating will really occur. Therefore the denominator is likely to stay positive and the prices are likely to remain bound.

3.3 Interaction of updating with banking

The ETS allows for banking and borrowing of allowances within 2005-2007 and within 2008-2012. Allowances cannot be transferred between phases. Banking of allowances allows one to smooth the price path over annual variations in climate-related energy consumption and business cycles and can incentivise for early emission reductions. As allowances are virtual, their banking does not create costs other than the opportunity costs of not using the money from selling allowances today. Therefore, with intertemporally arbitrage the allowance price is upward sloping with a market related interest rate.

Most market designs prohibit borrowing of future allowances. This implies that the allowance price might increase more slowly than the interest rate over time and the inter temporal arbitrage only sets a lower bound on today's price relative to tomorrow's.

Updating increases today's price. Therefore, if there is no saving of allowances in a world without updating, there will be no saving after updating is introduced. By contrast, if in a world without updating, allowances are saved from period t to period t+1, then the volume of savings will be decreased (or eliminated) with updating.

Assume saving of allowances from period t to period t+1. Then the relationship between prices in both periods is determined by the no arbitrage condition:

$$p_t = \beta\, p_{t+1} \qquad (11)$$

Banking implies that the emission balance no longer needs to be satisfied on a period by period basis, but can be shifted between periods. To simplify the calculations we assume saving only occurs in period t:

$$A(p_t) + A(p_{t+1}) = E(c_t) + E(c_{t+1}) \qquad (12)$$

Substituting c_t from (1):

$$A_t(p_t) + A_{t+1}(p_{t+1}) = E_t(p_t - u\beta p_{t+1}) + E_{t+1}(p_{t+1}),$$

using (11):

$$A_t(p_t) + A_{t+1}(p_t/\beta) = E_t((1-u)\, p_t) + E_{t+1}(p_t/\beta),$$

and differentiating with respect to u gives:

$$\frac{\partial p_t}{\partial u} = -\frac{\beta E_t'}{\beta A'_t + A'_{t+1} - \beta(1-u)E'_t - E'_{t+1}} p_t$$

Assuming linear and constant functions E and A gives:

$$\frac{\partial p_t}{\partial u} = -\frac{\beta}{1+\beta-\beta u-(1+\beta)A' \ / E'} p_t \tag{13}$$

The net change in emissions is therefore:

$$A'_t \frac{\partial p_t}{\partial u} + A'_{t+1} \frac{\partial p_{t+1}}{\partial u} = A' \frac{1}{1-\frac{\beta}{1+\beta}u-\frac{A'}{E'}} p_t \tag{14}$$

Comparing to the case without banking (7), the only difference in the impact on total allowances A_t+$A_{t+1}$is the component -β/(1+ β)u in the nominator. With banking (in the presence of saving) updating results in higher emissions. If u is small, the allowance price increase is split between period t and period t+1 (compare (13) and (4) and use (11)) such that the net impact on emissions is zero:

$$\frac{\partial p_{1,bank}}{\partial u} = \beta \frac{\partial p_{2,bank}}{\partial u} = \frac{\partial p_{1,no\_bank}}{\partial u} \frac{1}{1+\beta} \tag{15}$$

But if u is larger the increase in p_{t+1} makes future allowances allocated through updating in period t more valuable, and results in additional emissions in period t.

How is this reflected in the wholesale electricity prices? With one-off updating, the opportunity costs of emitting in period t+1 equals the allowance price. Therefore, electricity prices in period t+1 will increase with the rise in opportunity costs (exact link hinges on system configuration):

$$dc_{2,bank} = dc_{1,no\_bank} \frac{1}{\beta(1+\beta)} > 0\,, \tag{16}$$

In period one, prices will change according to (1) :

$$dc_{1,bank} = dp_{1,bank} - u\beta dp_{2bank} = (1-u)dp_{1,no\_bank} \frac{1}{1+\beta}\,. \tag{17}$$

Prices continue to increase, but only by a fraction of the increase observed without banking. The (dominant) first order effect with banking is that updating results in a reduction of banking. The experience with US SO_x program was that initial reductions in emissions were motivated by the opportunity to bank allowances. Updating might eliminate incentives to perform early emission reductions. Empirical analysis of allowance markets should therefore also consider whether a counterfactual without updating would have resulted in increased banking patterns and increased emission reductions.

4. Investment decisions and new entry/exit allocations

We now consider the incentives relating to new investment. Most EU governments have created 'new entrant reserves', a special pool of allowances available (usually for free) to cover emissions from new facilities that enter during the scheme's operation. The idea is to facilitate competition by lowering barriers to entry. However, new entrant allocation may distort the deployment of new low CO_2 technologies. Governments have also differed in their treatment of exit – whether, or for how long, facilities that close retain their emission allowances.

Specifically, we want to consider:

- impact of new entrant allocation on total installed capacity;
- impact of new entrant allocation on technology choice; and,
- impact of conditional allocation on closure decisions of power plants.

Investment is required to replace old plants and satisfy demand growth. The quantity of investment in a competitive market is determined such that the marginal invested unit of each technology makes zero expected profit.

We start by assessing an electricity system with only one generation technology, then move to a system with two technologies, and finally discuss how barriers to entry and investment risk impact the validity of these assumptions.

4.1 New entrant allocation - one technology

Consider deploying a new power generation unit with no lifetime limit. The net electricity sales is the revenue from selling electricity minus fuel costs $p_{elec,t}$. The cost of emitting CO_2 will be the product of the emissions per unit of production λ and the opportunity costs of allowances c. With new entry allocation, the new unit will receive a fixed number of allowances μ at their traded price p. Finally we have to consider the fixed costs per unit of production c_f. The profits of the marginal new entrant will be:

$$\pi = \sum_{t=0}^{\infty} \beta^t \left(p_{elec} - \lambda c\right) + \mu p - c_f . \qquad (18)$$

We assume that demand for electricity is growing in every period such that new entry is required. With no significant barriers to entry (18) is therefore satisfied when π=0. With continuous updating, the price stays constant and the opportunity costs of allowances equals today's price minus the discounted value of free allocation of tomorrow: c=(1-uβ)p. Substituting into (18) and using $\sum_{t=0}^{\infty} \beta^t = \frac{1}{1-\beta}$ gives:

$$p_{elec} = (1 - \mu - \beta(u - \mu))p + (1-\beta)c_f . \qquad (19)$$

Allowances A in the market have to equal total emissions. With one technology, total emissions will be equal to the demand for electricity $D(p_{elec})$ multiplied by the emission production factor λ such that:

$$\lambda D(p_{elec}) = A(p). \qquad (20)$$

Substituting (19) in (20) and differentiating with respect to the new entrance allocation μ shows how the allowance price changes with increasing new entrance allocation (where $D' = \partial D / \partial p_{elec} < 0$):

$$\frac{\partial p}{\partial \mu} = \frac{1+\beta}{1-\mu-\beta(u-\mu)-A'/(\lambda D')}\,p. \qquad (21)$$

Equation (21) shows that increasing μ will lead to an increase in p. Note that sum of free allocation μ and updating u is limited by the allowance budget, otherwise the denominator of (21) could turn zero. How will this feed through to the electricity price? If the allowance budget is fixed then, by (20), the amount of electricity that can be produced is fixed and therefore we can conclude that the electricity price will not be affected by the new entrant allocation. The up-front payment to new investors will be exactly offset by an increase in the allowance price and therefore future emission costs.

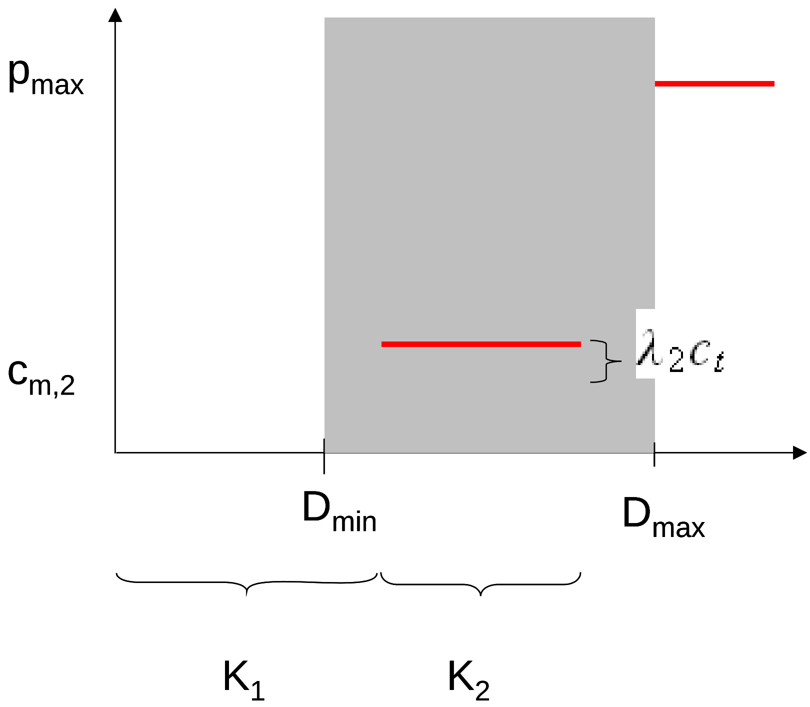
The situation is a little different if the allowance budget is increasing with increasing allowance price. In that case, A'>0, and whilst (21) shows that $\partial p / \partial \mu$ would still be positive, the influence of new entrant allocation on allowance prices will be lower than in the case with a fixed emissions cap (A'=0). As the allowance prices increase gives rise to an increase in A, for (20) to hold, electricity production will also rise. Higher electricity production requires higher electricity demand – and therefore the equilibrium electricity price is lower:

$$\frac{\partial p_{elec}}{\partial \mu} = \frac{A'}{\lambda Dl}\frac{\partial p}{\partial \mu} < 0$$

4.2 New entrant allocation - two technologies

Assume demand is satisfied with two different technologies. In equilibrium the marginal unit of each technology breaks even (π=0). To simplify the analysis we ignore updating and therefore set opportunity costs c of emissions equal to emission prices p. This also allows us to ignore the role of time and assume a one-off equilibrium decision.

Assume two technologies with fixed annual costs $c_{f,i}$, marginal costs $c_{m,i}$, CO_2 emissions λ_i, and installed capacity K_i. Assume demand is uniformly distributed between $D_{\min}$ and $D_{\max}$. For simplicity we assume that if $\sum K_i < D$ then the price will rise to the price $p_{\max}$ at which demand side response is assumed to set in at price p_{max}.



Let's assume technology one has lower marginal costs than technology two, $c_{m,1} + \lambda_1 c < c_{m,2} + \lambda_2 c$, and therefore technology 1 is dispatched first. Furthermore, let's normalise $c_{m,1} = 0$ and assume $\lambda_1 = 0$. Therefore, the average price over the year is:

$$p_{av} = (D_{\max} - \sum K_i) p_{\max} + K_2 (c_{m,2} + \lambda_2 c). \qquad (22)$$

Technology 1 is always running when prices exceed zero. Therefore, its average revenue equals the average price (the period of the year is normalised to 1 and so is $D_2 - D_1$). Its annual profits can be written as:

$$\pi_1 = (D_{\max} - \sum K_i) p_{\max} + K_2 (c_{m,2} + \lambda_2 c) - c_{f,1}. \qquad (23)$$

Technology 2 recovers its fixed costs during the period when prices reach the price cap. Its annual profits are therefore:

$$\pi_2 = (D_{\max} - \sum K_i)(p_{\max} - c_{m,2} - \lambda_2 c) + \mu c - c_{f,2}. \qquad (24)$$

In equilibrium the marginal unit of both technologies makes zero profits, $\pi_i = 0$. This allows us to calculate changes to the equilibrium level of installed capacity of both technologies.

An increase in the free allocation μ in (24) shows that $\partial \pi_2 / \partial \mu > 0$. Therefore, an increase in μ results in the construction of new generation capacity of type 2 and $\partial K_2 / \partial \mu > 0$. This shows that new entrant allocation can bias the investment decision towards the more carbon intensive technologies.

How is total installed capacity K_1+K_2 affected? Differentiating (23) with respect to μ gives:

$$\sum \frac{\partial K_i}{\partial \mu} = \frac{\frac{\partial K_2}{\partial \mu}(c_{m,2} + \lambda_2 c) + K_2 \lambda_2 \frac{\partial c}{\partial \mu}}{p_{\max}}. \qquad (25)$$

The first part of the nominator of (25) is positive and the second part negative. Therefore, we need to take a view on $\partial c/\partial \mu$ to assess the net impact of the new entrant allocation. Assuming that the total number of allowances is again elastic (A'>0), then:

$$A(c) = \lambda_2 K_2 (D_{\max} - K_1). \qquad (26)$$

Differentiating with respect to μ gives:

$$\frac{\partial c}{\partial \mu} = \lambda_2 \frac{\frac{\partial}{\partial \mu} K_2 (D_{\max} - K_1)}{A'}. \qquad (27)$$

Substituting (27) in (25) gives:

$$\sum \frac{\partial K_i}{\partial \mu} = \frac{\partial K_2}{\partial \mu} \frac{c_{m,2} + \lambda_2 c + K_2 \lambda_2^2 \frac{D_{\max} + K_2 - K_1}{\partial A/\partial c}}{p_{\max} + \frac{K_2^2 \lambda_2^2}{\partial A/\partial c}}. \qquad (28)$$

The term at the right hand side of (28) is positive, therefore free allocation to the emitting technology will not only shift investment towards this technology but also result in a net increase of emissions.

4.3 Contingent allocation

Allocation of CO2 allowances in some countries requires that the power station remains operational or even operates for a minimum number of hours per year. This differs from the US NO_x and SO_x programs that provided for unconditional allocation based only on the reference period. If the allocation is contingent on the availability of a power station, then an operator will be prepared to pay annual variable and fixed costs up to the value of the free allocation. This implies that more old power stations will stay online. The additional capacity reduces the scarcity value of capacity and therefore electricity prices. Contingent allocation has the same implications as the free new entrant allocation discussed in the previous section.

With contingent allocation the power price is reduced so electricity consumption is increased. In the absence of contingent allocation some of the unprofitable power stations might have been replaced by new build power stations. This would have resulted in more efficient production. Both effects imply that contingent allocation increases CO_2 emissions.

If a national allocation not only requires availability as a condition for the allowance allocation, but requires that a power station runs a minimum number of hours during the period, then the operator will run the power station even if the marginal costs exceed the wholesale price, so long as the incurred loss is less than the value of the allowances retained. It has the same implications as the previous mechanisms.

While some countries have specified conditional allocation within a national allocation plan, no country has committed to totally unconditional allocation for the first Kyoto period. Even if the

Commission or Member States were to confirm that current emissions are not part of the reference period to quantify CO_2 allowance allocation for the first Kyoto period, power station operators might expect that they have to keep their power stations available until the allocation is confirmed to benefit from the allocation. This provides an additional component of conditional allocation.

5. Summary analytic results

Table 2 summarises the analytic results for the different cases. It shows that in all those cases that have been analysed, updating and new entrant allocation will increase the allowance price E and will decrease the opportunity costs, which generators face for emitting CO2. Lower opportunity costs will result in lower wholesale market prices.

	Allowance price (p)		Emissions (E)		Opportunity costs (c)	
	base period	next period	base period	next period	base period	next period
Initial updating			+		-	
One-off updating	+	+[2]	+[1]	+[1,2]	-[1]	-[2]
Continuous updating	+	+	+[1]	+[1]	-[1]	-[1]
New entrant alloc 1 tech	+		+[1]		-[1]	
New entrant alloc. 2 tech	+		+[1]			

[1] Only with flexible allowance budget (A'>0) + increased by allocation
[2] Only with banking - reduced by allocation

Table 2 Distortions caused by different allocation mechanisms

If an increase of the allowance price results in an increase of the number of allowances in the market, then all analysed cases of updating and new entrant allocation will result in an increase of aggregate emissions.

As allocation mechanisms vary, the extent to which allowance prices will be inflated will also vary between countries and sectors. This can create additional distortions, as illustrated by the following example. Imagine two symmetrical regions. Symmetry would suggest that both regions achieve the same emission reductions and we observe the same allowance prices in both regions. If updating inflates allowance prices in region A, then trade between the regions would imply that allowances are sold from region B to region A until prices are arbitraged. This implies that additional emission reductions are achieved in region B and lower reductions are achieved in region A. As the efficient solution would have been symmetric reductions the asymmetric updating of tradable allowances resulted in an inefficient solution.

6. Numerical implications

To support the analytical analysis we have used a dispatch model of the UK power system. For this purpose we have used the Integrated Planning Model (IPM®), developed by ICF Consulting. It is a linear optimisation formulation and selects investment options and dispatches generation and load management resources to meet overall electric demand today and on an ongoing basis over the chosen planning horizon.[7]

We expand the model such that it can calculate the equilibrium for a market with updating. Changes in other environmental regulation, in particular the large combustion plant directive covering SO_x and NO_x also have significant implications for the profitability of power plants. We do not activate this option during the runs such that the pure effect of CO_2 constraints can be better interpreted. Table 3 shows the CO_2 allowance prices which are determined exogenously. This reflects either the limited impact of one country on the European allowance prices or the aspect that government policy determines CO_2 emission reduction targets to achieve effective but not too expensive CO_2 allowance prices.

Year	2005-2007	2008-2012	2013-2017	2018-
Euro/tCO_2	10	15	15	20

Table 3 Allowance prices in base case

In the model runs gas price are assumed to start at 5.20 Euro/MMBtu in 2005 and drop to 4.10 Euro/MMBtu by 2020. Coal price start at 2.66 Euro/MMBtu in 2005 and drop to 2.25 Euro/MMBtu by 2020.

Figure 3 shows that implementing CO_2 constraints increased the "all-in" power price from the case without CO_2 emission constraints to the base case. With updating a power station emitting one additional unit of CO_2 will receive 0.7 units of additional allowances in the following period. This significantly reduces opportunity costs of CO_2 emissions and results in only half the increase of power prices from CO2 constraints.

If new entrants obtain CO_2 allowances in their first period of existing (NER), then new power plants require less additional revenue from scarcity prices (e.g. capacity payments) to break even and the equilibrium power price falls.

[7] For further information on the IPM® and use of the model by the US Environmental Protection Agency's refer to http://www.epa.gov/airmarkets/epa-ipm/.

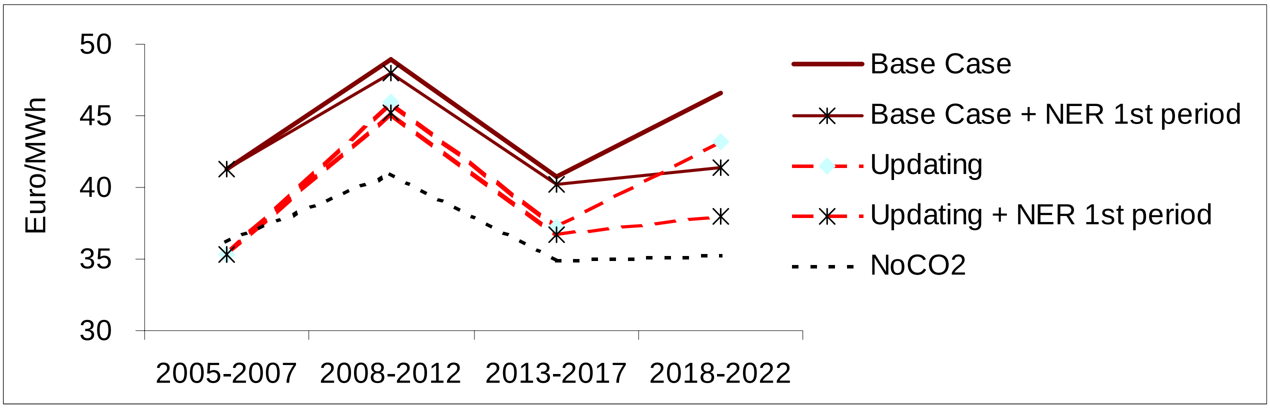


Figure 3 Price reflects energy-weighted average wholesale power price across UK

Figure 4 shows, that the CO_2 constraints in the base case results in large amounts of new investment in CCGT to replace coal stations. With updating the opportunity costs of CO_2 emissions are reduced and hence more old power stations continues to run, reducing the dash for gas.

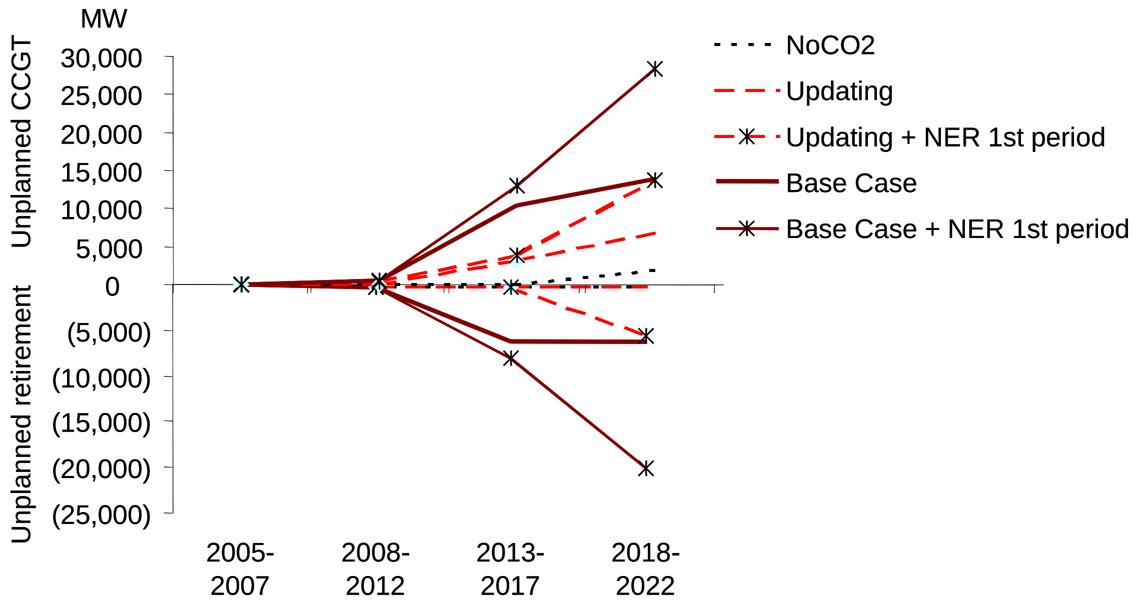


Figure 4 Cumulative installed capacity in CCGT and retired capacity in base case

The figure also indicates that due to updating the opportunity to obtain future allocation based on today's emission prevents the retirement of plants.

Finally, Figure 5 illustrates how total emissions change in all three scenarios. Updating reduces the impact of ETS by 50%.

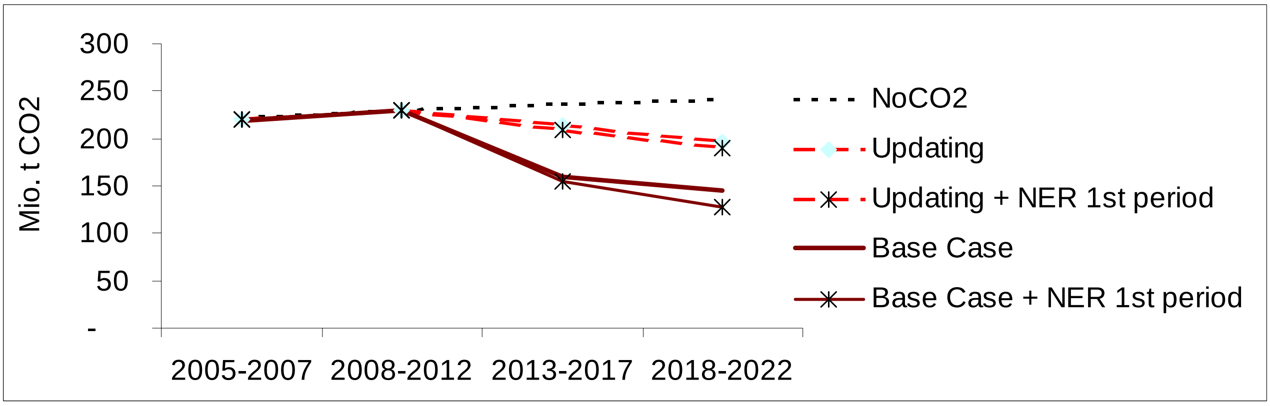


Figure 5 Total CO_2 emissions in the UK power sector base case

New entrant allocation increases the effectiveness of ETS. The new entrant allocation supports the earlier construction of CCGT and hence a shift from coal to gas production. This dynamic impact is not reflected in the equilibrium analysis in section 4, which predicted a more CO_2 intensive technology mix as a result of new entrant allocations of CO_2 allowances. A possible explanation for this is that we are in a dynamic environment – and dynamic effects have to be assessed in the transition period. But at the same time, the dynamic effects predicted by a numerical model can be sensitive to model assumptions. In our choice of technology costs and fuel prices only CCGT power stations are competitive. With higher CO_2 prices or higher gas prices this might no longer hold, and then the new entrant allocation might prevent or reduce the investment in lower CO_2 technologies instead of CCGT or might result in the construction of more CO_2 intensive coal power stations instead of CCGT.

Figure 6 shows the CO_2 emissions at twice the allowance prices from the base case in Table 3. They result in a shift of the merit order and therefore there are already emission reductions in 2005-2007 that were not observed in the base case.

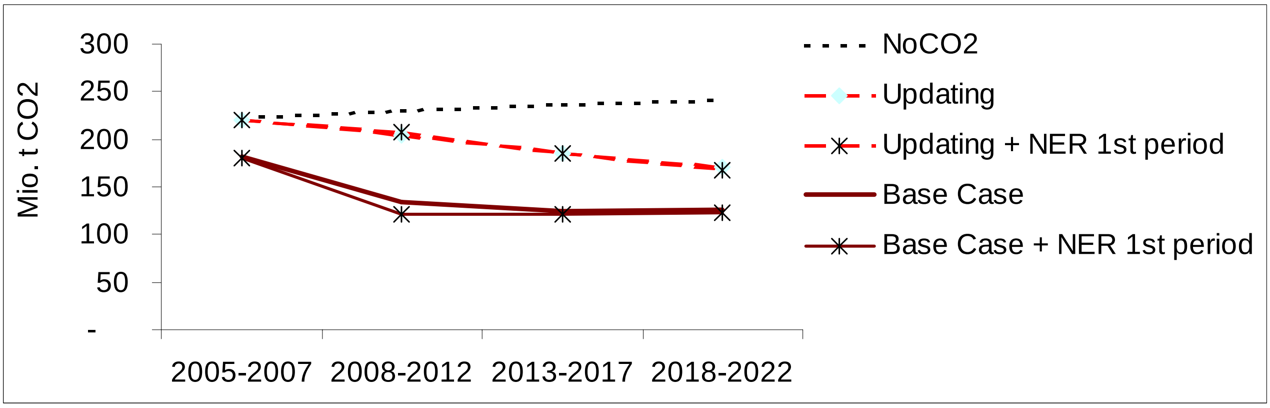


Figure 6 Total CO_2 emissions in the UK power sector – double CO_2 prices

Figure 7 illustrates that the higher CO_2 prices also induce earlier retirement of coal plants and construction of CCGT plants.

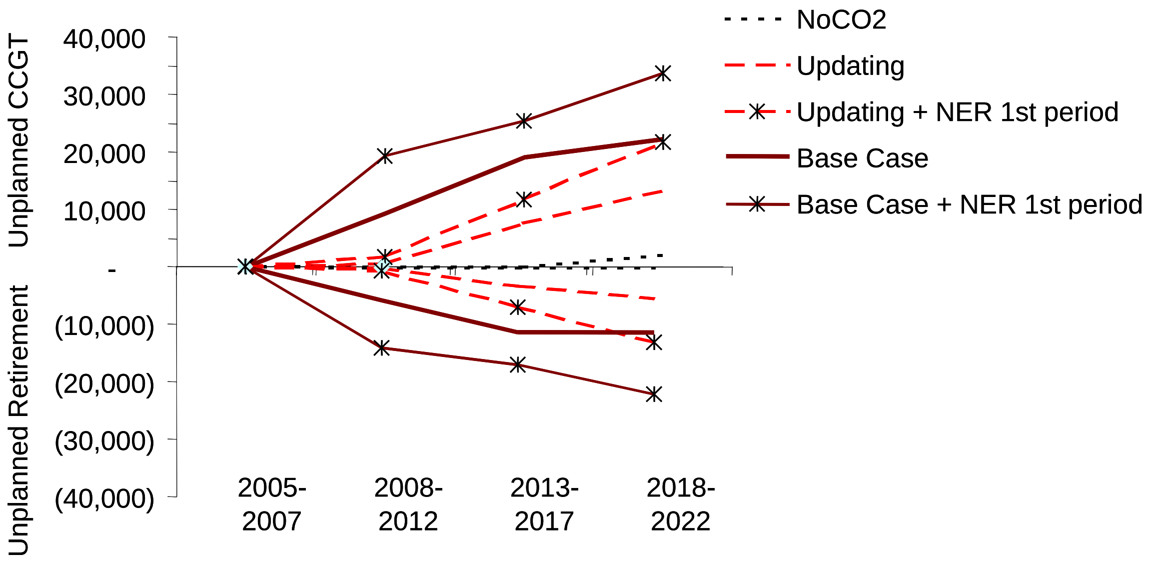


Figure 7 Cumulative installed capacity in CCGT and retired capacity, double CO_2 price

However, the final emission volume in 2018-2022 is only reduced by 10% from 146 Mio. t CO_2 in the base case to 126 Mio t CO_2 in the case with double the CO2 prices. It is not surprising that the impact is so small, as coal based generation in 2018-2022 is already in the base case reduced to 15% of today's level such that more CCGT with higher CO_2 prices allows only limited additional emission reductions. What would be required are CO_2 free technologies, like renewables. To focus on the CO_2 allocation we only implemented a 10.6 GW of renewables deployment by 2020 which stayed constant in all scenarios.

The updating factor we apply in the model is likely to be at the high end. Figure 8 shows the impact on prices if a unit of emission only provides 0.35 additional free allowances in the subsequent period, instead of 0.7 as in the previous example.

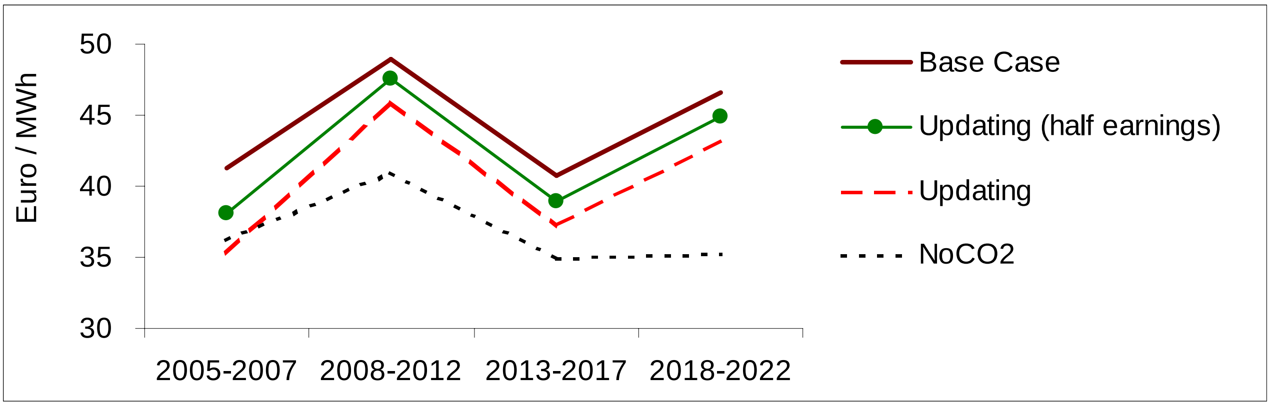


Figure 8 All in power prices for different levels of updating, base case CO_2 price

Electricity prices reduce approximately linear with the updating factor. In our model this relationship is also observed for the CO_2 emissions and for the volume of new build CCGT. However, the retirement stays at less than 10% of the volume observed in the base case even if the updating factor is halved. This shows the existence of trigger levels.

The numerical model showed that all allocation provisions of the ETS reduce the wholesale electricity price compared to the price observed if allowances were grandfathered or auctioned.

Updating provisions delay a shift in the merit order, investment in less CO_2 intensive CCGT and hence CO_2 emission reductions. With updating or no-closure conditions most CO_2 intensive power stations are retained on the system.

The new entrant allocation illustrates the value of combining analytic and numeric results. The simulation shows that new entrant allocation accelerates the investment into lower CO_2 intensive CCGT plants resulting in earlier CO2 emission reductions. This positive dynamic effect could be out weight if new entrant allocation distorts the technology choice for new investment, e.g. biases towards coal instead of gas or gas instead of renewables. In the simulation the bias introduced was smaller than the cost differences between coal, gas and renewable technologies and did therefore not affect technology choice. But this is not true for all fuel, CO_2 allowance and technology price assumptions.

7. Elasticity of Allowance supply - Linking Mechanisms

The ability to offer 'new entrant' allocations is one very specific and narrow aspect of a broader property of the EU ETS, namely that it is a partially open system: the total number of allowances in the trading market is not fixed, but is conditional both within any period, and in future periods.

Within the present (2005-7) period, the total number of allowances available is affected by (i) new entrants, as discussed, and (ii) by the import of 'emission credits' through the Kyoto Protocol's project mechanisms, specifically the Clean Development Mechanism that allows generation of credits from emission-reducing projects in developing countries.

In the next (Kyoto CP1) phase, each Member State has a cap on total national emissions, the openness of the EU ETS itself increases further. At the stage of *allocation*, the total available to the EU ETS facilities can be changed through:

(1) countries can shift internal allocation from the non-covered sector to the covered sector;

(2) Member States can choose to buy Emission Reduction Units (ERUs) from Joint Implementation (JI) projects and Certified Emission Reductions (CERs) from Clean Development Mechanism (CDM) projects;

(3) Member States could purchase allowances directly from other industrialised countries, notably the surplus available in potentially very large amounts from Russia and Ukraine (known as "hot air" trading).

In addition, at the stage of *operation*, the number of allowances in the EU can be increased by company purchases of ERUs and CERs. Thus, the aggregate quantity of emission certificates available to EU ETS market participants is a function of the CO_2 price:

- in the first period because that may affect the total that Member States are willing to allocate to their capped sectors in the Kyoto period;

- in the second (Kyoto) period, when the price will determine the level of emission credit imports.

In principle, Kyoto's project mechanisms generate emission credits only when they offer *additional* emission savings, and thus represent a geographical displacement of the emission reduction effort; as long as an increased allowance price only results in an increase of JI and CDM projects, there will be no global net effect on CO2 concentrations.

However, current analysis suggests that Russia and the Ukraine have excess AAUs that exceed the demand of the remaining Kyoto member states (excluding the US). Any increased use of these AAUs will result in a net increase of global CO_2 emissions. To the extent that allowances are purchased from countries with 'Hot Air', this does not involve any corresponding emission reductions (and the governance of ERU transfers from such countries may be similarly weak). Such trades may increase overall global emissions.

A third mechanism, through which higher CO_2 allowance prices can result in higher global CO_2 emissions are the negotiations for future reduction targets. If national governments assess the economic implications of CO_2 constraints based on the CO_2 allowance prices, then inflated CO_2 prices will reduce the motivation for national governments to negotiate more stringent reduction targets.

A final displacement effect may arise if multinational energy intensive industries change their production patterns to produce more from outside the EU ETS zone, or if industries relocate facilities, or import more from outside the EU ETS zone. Indeed if such production is at facilities that are less efficient than those in the EU, this could lead to a net increase.

In a subsequent paper, we will explore the impact of the essential openness of the EU ETS on the overall emission incentive effect of the EU ETS.

8. Conclusion

Our analysis shows that CO_2 allowances allocation mechanisms used in the European Union's Emission Trading Scheme (ETS) distorts electricity prices. If tomorrow's allocation can be influenced by today's CO2 emissions, this can create a wedge between allowance prices and opportunity costs. Allowance prices can be inflated above the level they would take in a cap-and-trade program with pure auctioning of allowances or one-off allocation based on historic emissions. This inflation can distort inter-sectoral, international and inter-temporal production and emission reduction decisions.

With this form of updating, the opportunity costs for CO2 emissions can be reduced not only below the allowance price but below the efficient allowance price. As a result final electricity prices may not reflect the environmental externality inducing excessive consumption and limiting the attractiveness of energy efficiency programmes.

The new entrant allocation can furthermore distort the technology choice for new power plants away from less CO2 intensive plants towards more CO_2 intensive technologies.

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