Can hedging stabilize carbon markets?

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Abstract

CO_2 hedging by power generators can stabilize the demand-supply balance at lower discount rates than CO_2 banking by speculative investors, when hedging can meet the surplus of CO_2 allowances.

First, we model the two factors determining hedging demand for CO_2 allowances in the power sector as identified in semi-structured interviews. Power companies sell power sold several years ahead of production and acquire fuels and CO_2 to hedge price changes. The volumes and the period are a corporate strategy decision. With deviations of forward prices from expectations the volume of power sold forward and the allocation to different generation assets is adjusted. This can result in adjustments to the CO_2 hedging demand in the corridor of 1.2 to 1.4 billion t.

Second, we model the interactions of CO_2 hedging demand in the power sector, CO_2 banking by speculative investors and CO_2 price dependent emission levels in a two-period framework. There are different levels of stabilization of the CO_2 price with banking in response to the deviation of surplus from median hedging volume in the power sector. Once the surplus exceeds the hedging demand, the price falls steeper with each additional tonne of CO_2. This points to the value of reducing the surplus of CO_2 allowances in European Emissions Trading System by about 1.3 billion t CO_2 to ensure hedging can make a significant contribution to stabilize carbon prices.

1. Introduction

In the European Emissions Trading System (EU ETS), the supply of CO_2 allowances is fixed several years in advance and thus does not respond immediately to variations in demand. In 2007, at the end of the first trading phase of the EU ETS, spot prices dropped to 0 Euro/ t CO_2, because supply of expiring CO_2 allowances exceeded demand (Chevallier 2011; Fell, Moore et al. 2011). In principle this should not happen again, because in the second trading phase, between 2008 and 2012, and in the third trading phase, between 2013 and 2020, surplus allowances can be banked for future usage. Banking constitutes additional demand for CO_2 allowances beyond the need to cover the emissions by the end of the year. Market participants have an incentive to bank, i.e. hold CO_2 allowances from one year to the next, if they expect future carbon prices to increase with the rate of interest (Cronshaw and Kruse 1996). Through banking expectations on future market scarcity can therefore be priced into current carbon prices. As a result of banking, the carbon price in the EU ETS did not drop to zero during the second trading phase, despite a surplus of allowances.

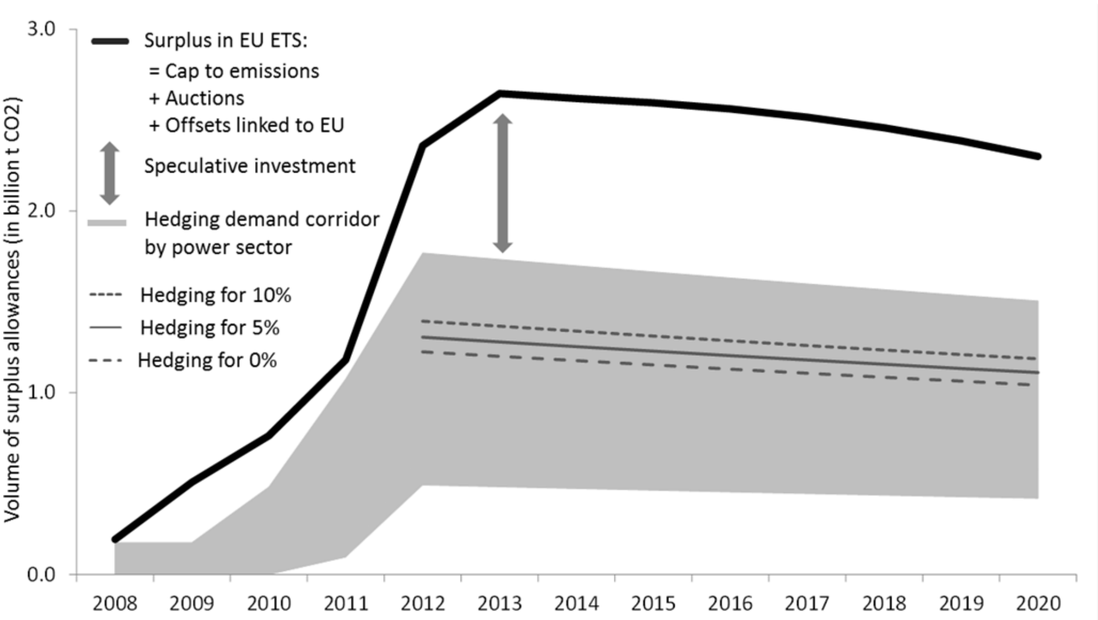
The cumulative surplus of allowances is estimated to reach 2.7 billion in 2013 (Neuhoff, Schopp et al. 2012). Demand for this surplus derives from three types of actors banking CO_2 allowances: arbitrageurs, hedgers and speculators. We model hedging demand by the power sector and the interaction with speculative investment and CO_2 price dependent emission levels.

In the EU ETS the hedging demand for CO_2 allowances by the power sector constitutes a main driver for scarcity and thus prices of CO_2 allowances. They hold CO_2 allowances beyond what they need to cover their annual emissions, as they use these allowances to hedge the carbon prices for producing power that they sell several years forward. CO_2 hedging demand has gradually increased since 2008 because after 2013 power generators in Western Europe will no longer receive free CO_2 allowances.

The aggregate hedging demand can vary from one year to the other, because power generators have flexibility in adjusting the power forward sales, and thus also fuels and CO_2. In theory, power companies can either give priority to all fossil generation capacity to hedge power sales (maximum hedging volume) or they can give priority to all renewable generation capacity to hedge power sales (minimum hedging volume). The grey hedging corridor in Figure 1 depicts this flexibility resulting from the power generation mix.

Interviews suggest that power companies follow risk management procedures and thus have less flexibility in adjusting their CO_2 hedging volume. We model the two factors determining hedging demand for CO_2 allowances in the power sector as identified in 13 semi-structured interviews. With deviations of forward prices from expectations by companies the volume of power sold forward and the allocation to different generation assets is adjusted. The more that expectations exceed CO_2 forward contract prices three years ahead of production, the more that firms deviate from their hedging schedule contracting bigger volumes of coal, gas and thus CO_2 three years ahead and less later on. This can result in adjustments to the CO_2 hedging demand between 1.2 to 1.4 billion t (dotted lines).

Figure 1: Cumulative surplus of CO_2 allowances and hedging demand



Source: Own calculation based on Neuhoff (2012)

We then model the equilibrium in the CO2 market for a simplified two period framework. In addition to the hedging demand by the power sector, we include the speculative investment and CO_2 price dependent emission levels in a two-period framework. There are different levels of stabilization of the CO_2 price with banking in response to the deviation of surplus from median hedging volume in the power sector. This points to the value of reducing the surplus of CO_2 allowances in EU ETS by about 1.3 billion t CO_2 to ensure hedging can make a significant contribution to stabilize carbon prices.

The paper is structured as follows: Section 2 reviews the relevant literature on banking. Section 3 describes the model to quantify CO_2 hedging demand of the power sector and the demand from speculative investment in CO_2 allowances. Section 4 presents the results from the modeling and discusses these in the context of expert interviews with 13 power generators. Section 5 draws conclusions.

2. Literature

Banking of CO_2 allowances can be analyzed first, theoretically and empirically, as an instrument to achieve efficiency of emissions reduction cost and, second, through the lens of portfolio theory, as an asset in an investment portfolio or as input in the production process.

First, the intertemporal flexibility of banking can theoretically reduce overall mitigation cost, as firms are allowed to hold CO_2 allowances for future use and invest in emissions-reducing technologies and thus distribute their emissions over time. With banking the carbon price follows the Hotelling's rule and thus increases with the rate of interest (Rubin 1996). If firms' discount rates are higher than that of the social planner, unlimited banking and borrowing might not lead to the social optimum, as firms borrow more allowances from the future and bank less than it would be socially optimal. This is because the discount rates of firms will determine how the carbon price increases (Leiby and Rubin 2001).

Although empirical evidence regarding the efficiency of banking of allowances does not yet exist for the EU CO_2 emissions trading scheme, it does exist for the US SO_2 emissions trading scheme. Ellerman and Montero (2007) provide empirical evidence for the efficient volume of banking that allowed reducing overall abatement cost for the SO_2 US Acid Rain program. To evaluate the SO_2 allowance bank the authors assumed discount rates of 3 to 5%. These correspond to discount rates that are assumed in impact assessments of the EU ETS: Price projections for 2020 prices of more than 30 EUR/t CO_2 relative to prices of 20 EUR/t CO_2 in 2008 imply discount rates of 3 to 5% (European Commission 2008; Department of Energy and Climate Change 2009). In this paper we model the hedging and speculative demand for CO_2 allowances assuming that discount rates are higher if banking of CO_2 allowances is pursued as speculative investment and not for hedging purposes.

Second, the banking of CO_2 allowances can be analyzed with the instruments of portfolio optimization. Three types of actors bank CO_2 allowances: arbitrageurs, hedgers and speculators. Arbitrageurs, e.g. banks make profits by exploiting price differences between spot and forward prices. They buy CO_2 allowances and simultaneously sell financial derivatives and thus are not exposed to changes in CO_2 prices. Hedgers hold CO_2 allowances for future use, e.g. as input in their production process. Speculators buy CO_2 allowances in expectation that the price will rise more than reflected in the market. They bear the risk that their expectation is not realized and thus require higher rates of return than hedgers (Bailey 2005).

Speculators can buy CO_2 allowances as part of an asset portfolio including equity, bonds or alternative investments such as power generation technologies. To select the best portfolio, Markowitz (1952) proposes to weigh maximizing the expected return of the portfolio and minimizing the variance of portfolio's return, as this yields a diversified portfolio for a wide range of means and variances. In this case a mean-variance approach could be used to identify optimal portfolios that lie on the efficient frontier between risk and return. Diversifying a portfolio might reduce risk, if the assets' returns do not move into the same direction. Thus, Chevallier (2009) and Mansanet–Bataller and Pardo (2011) suggest that including CO_2 allowances in a portfolio of equity, bonds and energy assets can reduce risk. This derives from their finding that CO_2 allowances are linked in particular to the power market and to the fuel switching between coal and gas as well as to the policy design of the carbon market, but not so much to the movement of equity and bond assets. However, to make CO_2 allowances an attractive investment option across conservative investors, the perceived risk has to decline. The current price volatility and difficulty in modeling policy uncertainty may have increased risk perceptions.

Hedgers such as power generators treat CO_2 allowances mainly as input cost in a power generation portfolio. To hedge exposure of their generation portfolio to price changes, power generators can sign contracts for selling power and buying the input factors such as fuels and CO_2 in advance of production at future markets. Or they can take the risk and acquire contracts on the spot market, usually one day ahead of production. Kleindorfer and Li (2011) aim to identify optimal generation portfolios that lie on the efficient frontier, accounting for CO2 as part of the generation cost. The portfolios consist of physical generation assets and financial derivatives such as forwards or options to buy (call) or sell (put). The power companies choose the mix of financial instruments in their generation portfolio, so as to maximize the expected profit from sales and purchases of energy assets given a value at risk constraint. In addition to identifying the optimal portfolio of financial instruments, power companies can decide on the timing of the acquisition of CO_2 allowances. In the framework of Kleindorfer and Li (2011), the volume of CO_2 allowances to buy or sell in each month depends on the current CO_2 price of the end of year future contract in relation to its mean. If the CO_2 price equals its mean, the power company contracts CO_2 so as to cover each month of its emissions, accounting for the volume of allowances they have banked or were allocated in previous months. If the CO_2 price is below its mean and can thus be expected to increase in the following month, it is profitable to contract more CO_2 in this month and vice versa. This result is driven by the assumption that the CO_2 prices will move back to its mean over time (mean reverting process).

Optimal portfolio theory, however, has limited applicability for power hedging in practice. Thus, portfolio optimization aiming at reducing volatility of prices is based on dependencies between assets' returns. However, dependencies between CO_2 and power prices can be complex and non-linear. Empirical studies find positive impacts on CO2 prices from gas and oil prices and negative impacts from coal and positive impacts of CO_2 prices on power prices (Alberola and Chevallier 2009; Mansanet–Bataller and Pardo 2011). Blyth et al. (2009) argue that carbon prices are also influenced by climate policy developments such as emissions reduction targets or renewable energy and energy efficiency instruments. The assumption of linear dependencies between CO_2 prices and power only holds as long as carbon prices are either very low or very high. The variable cost of the fuel that is at the margin, i.e. the fuel that is used to produce an additional unit of power, determines the power generation cost (Burtraw and Palmer 2008). Since coal has higher carbon intensity than gas, power price responses to changes in CO_2 prices are higher when coal is at the margin (Fell 2010). This means that for very low carbon prices coal is at the margin and for very high carbon prices gas is at the margin. In between, where the fuel that is at the margin changes, the relationship is not linear. Power generators aiming at stable returns from power sales may manage these risks by hedging across the portfolio of generation technologies.

The actual volume of CO_2 allowances that firms hold as financial contracts for hedging or speculation purposes is not publicly known. Data exist only on the volume of allowances that are allocated to firms participating in the EU ETS as well as the volume of allowances that is used to cover emissions. Few papers estimated the hedging demand for CO_2 allowances in the EU ETS. According to Eurelectric (2009) power generators sell about 10 to 20% of their power three years ahead, 30 to 40% two years ahead and 60 to 80% one year ahead of production. They argue that the power sector will require 1.3 billion CO_2 allowances by the end of 2012 in order to hedge power sales through 2015. Point Carbon (2011) derives lower estimates, as they do not account for the use of international offsets that can also be used as part of the hedging portfolio. According to their calculations, the power sector will need 650 million CO_2 allowances by the end of 2012 and 950 million CO_2 allowances by 2013.

The previous literature does not account for both the strategy of power generators to hedge across the portfolio and the flexibility of power generators in adjusting the hedging demand for CO_2 allowances to their expectations of future prices and the interaction with speculative investment at higher discount rates.

3. Model of hedging demand for CO_2 allowances

3.1. Hedging demand of power firms

We formulate a partial equilibrium model in order to analyze the factors that determine CO_2 hedging volume. The model assumes a firm producing power of E per year. The firm produces power from coal C and gas G. The coal-fired power plants produce power with a thermal efficiency of f^c and the gas plants with a thermal efficiency of f^g. The CO_2 hedging volume depends on the volume of power sold forward. To reduce the exposure to price risks and profit volatility from power production, firms sell power several years in advance of production. To secure prices of the power generation inputs, firms buy coal, gas, or CO_2–free generation technologies in advance. Therefore, firms also buy CO_2 allowances in advance to cover future emissions from carbon intensive power generation technologies.

In the model the firm sells in the years prior to the production power on forward contracts and at the same time acquires forward contracts for the fuels required for production. Within the last year the firm contracts the remaining power to match projected generation. The model focuses on the forward contracting strategy, as this has the largest impact on total hedging demand, and does not capture adjustments to contracts in the final year. We will first illustrate the approach using a two period model, and subsequently present result calibrated to the empirical observed contracting strategy and therefore allowing for up to four years of forward contracting.

Interviews with 13 power generators[1] suggest that the volume and the period for which power is sold forward is a corporate strategy decision. Based on its expected generation portfolio, the firm formulates a hedging schedule: $\gamma_1\%$ of power are sold in year one and $\gamma_2\%$ of power are sold in year two. In the interviews, it was also reported that open positions in power sales have to be avoided. This implies that the power forward sale in year one has to be matched by forward contracts for the inputs required to produce the power $e_1 = c_1 + g_1$. Several power generators reported that they prefer to hedge across the portfolio of their generation assets, rather than with a strong emphasis on one specific generation technology. Accordingly, the firm buys $\gamma_1\%$ of coal and gas in year one and $\gamma_2\%$ of coal and gas are acquired in year two. However, companies can deviate from this proportional hedging schedule. To reflect both the preference to hedge across the portfolio and the opportunities for adjustment, deviations from the formulated hedging schedule are captured as quadratic penalty:

$$\alpha((\gamma_1 * C - c_1)^2 + (\gamma_1 * G - g_1)^2). \tag{1}$$

When firms' expectations about future energy and carbon prices differ from forward contract prices in the market it impacts CO_2 hedging volume. For example, if carbon prices are currently low, but are expected to increase, this creates an incentive for power generators to prioritize hedging future power sales with generation by carbon intensive assets, as this allows for early contracting of carbon at lower prices. As a result, the hedging demand for CO_2 increases. The interviews suggest that this prioritization of generation technologies is based on expected profits. Of the power that the firm will produce in year two it sells e_1 in year one and $E - e_1$ in year two. In year one the firm thus expects revenues that depend on the forward prices in year one p_1^e and the expected price in year two $E(p_2^e)$:

$$e_1 \; * p_1^e + (E - e_1)\, E(p_2^e). \tag{2}$$

The firm also signs forward contracts in year one for the coal and gas inputs to produce the power, and acquires the remaining fuel volumes in year two:

$$c_1 * \frac{p_1^c}{f^c} + (C - c_1)\frac{E(p_2^c)}{f^c} + g_1 * \frac{p_1^g}{f^g} + (G - g_1) * \frac{E(p_2^g)}{f^g}, \tag{3}$$

The firm does not hedge more than it can generate ($C \geq c_1$; $G \geq g_1$). In addition, the firm needs to buy carbon to hedge the power production from coal and gas. The required volume of CO_2 allowances to cover the emissions depends on the carbon intensity of the coal plants i_{CO2}^g and of the gas plants i_{CO2}^g. The firm considers forward contract prices for CO_2 allowances in year one p_1^{CO2} and its expectations of carbon prices for year two $E\left(p_2^{CO2}\right)$. The expected carbon costs are:

[1] We conducted interviews with experts from 13 power generators: Badenova, Dong, EDF, Enel, EnBW, GDF Suez, Iberdrola, MVV Energie, Enercity, Stadtwerke München, RWE, Statkraft, Vattenfall. These companies produce 56% of European power production (Annual reports 2010)

$$c_1 * i^c_{CO2} * p_1^{CO2} + (C - c_1)\, i^c_{CO2} * E(p_2^{CO2}) + g_1 * i^g_{CO2} * p_1^{CO2} + (G - g_1)\, i^g_{CO2} * E(p_2^{CO2}). \tag{4}$$

Thus, the power firm chooses the contract volume of coal and gas in year one, so as to maximize the expected profit (combining equations (1) to (4) and substituting $e_1$by $c_1 + g_1$):

$$\max_{c_1,g_1} E(\pi) = \max_{c_1,g_1} -(c_1 + g_1)(E(p_2^e) - p_1^e) + (C + G)\, E(p_2^e) + c_1\left(\frac{E(p_2^c) - p_1^c}{f^c} + i^c_{CO2}(E(p_2^{CO2}) - p_1^{CO2})\right) - C\left(\frac{E(p_2^c)}{f^c} + i^c_{CO2} * E(p_2^{CO2})\right) + g_1\left(\frac{E(p_2^g) - p_1^g}{f^g} + i^g_{CO2}(E(p_2^{CO2}) - p_1^{CO2})\right) - G\left(\frac{E(p_2^g)}{f^g} + i^g_{CO2} * E(p_2^{CO2})\right) - \alpha((\gamma_1 * C - c_1)^2 + (\gamma_1 * G - g_1)^2). \tag{5}$$

The profit function is subject to the following constraints:

$$C - c_1 \geq 0, \tag{6}$$

$$G - g_1 \geq 0, \tag{7}$$

$$c_1,\ g_1 \geq 0. \tag{8}$$

The associated Lagrangian is:

$$\max_{c_1,g_1,\lambda_1,\lambda_2} L = \max_{c_1,g_1,\lambda_1,\lambda_2} -(c_1 + g_1)(E(p_2^e) - p_1^e) + (C + G)\, E(p_2^e) + c_1\left(\frac{E(p_2^c) - p_1^c}{f^c} + i^c_{CO2}(E(p_2^{CO2}) - p_1^{CO2})\right) - C\left(\frac{E(p_2^c)}{f^c} + i^c_{CO2} * E(p_2^{CO2})\right) + g_1\left(\frac{E(p_2^g) - p_1^g}{f^g} + i^g_{CO2}(E(p_2^{CO2}) - p_1^{CO2})\right) - G\left(\frac{E(p_2^g)}{f^g} + i^g_{CO2} * E(p_2^{CO2})\right) - \alpha((\gamma_1 * C - c_1)^2 + (\gamma_1 * G - g_1)^2) + \lambda_1(C - c_1) + \lambda_2(G - g_1). \tag{9}$$

The first order (Karush–Kuhn–Tucker) conditions are the following:

$$\frac{\partial L}{\partial c_1} = -(E(p_2^e) - p_1^e) + \frac{E(p_2^c) - p_1^c}{f^c} + i^c_{CO2}(E(p_2^{CO2}) - p_1^{CO2}) + 2\alpha\,(\gamma_1 * C - c_1) - \lambda_1 = 0, \tag{10}$$

$$\frac{\partial L}{\partial g_1} = -(E(p_2^e) - p_1^e) + \frac{E(p_2^g) - p_1^g}{f^g} + i^g_{CO2}(E(p_2^{CO2}) - p_1^{CO2}) + 2\alpha\,(\gamma_1 * G - g_1) - \lambda_2 = 0, \tag{11}$$

$$\frac{\partial L}{\partial \lambda_1} = C - c_1 \geq 0, \qquad \lambda_1 \geq 0, \qquad (C - c_1)\lambda_1 = 0, \tag{12}$$

$$\frac{\partial L}{\partial \lambda_2} = G - g_1 \geq 0, \qquad \lambda_2 \geq 0, \qquad (G - g_1)\lambda_2 = 0, \tag{13}$$

$$c_1,\ g_1 \geq 0. \tag{14}$$

With $\lambda_1 = 0, \lambda_2 = 0$ and $C - c_1 \geq 0, G - g_1 \geq 0$ (internal solution) equations (10) and (11) can be rewritten as:

$$c_1 = \frac{1}{2\alpha}\left(-(E(p_2^e) - p_1^e) + \frac{E(p_2^c) - p_1^c}{f^c} + i_{CO2}^c(E(p_2^{CO2}) - p_1^{CO2})\right) + \gamma_1 * C, \quad (15)$$

$$g_1 = \frac{1}{2\alpha}\left(-(E(p_2^e) - p_1^e) + \frac{E(p_2^g) - p_1^g}{f^g} + i_{CO2}^g(E(p_2^{CO2}) - p_1^{CO2})\right) + \gamma_1 * G. \quad (16)$$

If expectations for power, coal and gas match forward contracts for these commodities, equations (15) and (16) reduce to:

$$c_1 = \frac{1}{2\alpha} * i_{CO2}^c(E(p_2^{CO2}) - p_1^{CO2}) + \gamma_1 * C, \quad (17)$$

$$g_1 = \frac{1}{2\alpha} * i_{CO2}^g(E(p_2^{CO2}) - p_1^{CO2}) + \gamma_1 * G. \quad (18)$$

From the optimal coal and gas volumes contracted in year one results the hedging volume of CO_2 allowances that are acquired in year one to hedge production in year two:

$$\begin{aligned} h_1 &= c_1 * i_{CO2}^c + g_1 * i_{CO2}^g \\ &= \left(\frac{1}{2\alpha} * i_{CO2}^c(E(p_2^{CO2}) - p_1^{CO2}) + \gamma_1 * C\right) i_{CO2}^c + \left(\frac{1}{2\alpha} * i_{CO2}^g(E(p_2^{CO2}) - p_1^{CO2}) + \gamma_1 * G\right) i_{CO2}^g. \end{aligned} \quad (19)$$

Equation (19) shows that if expectations of future carbon prices exceed forward contracts for CO_2 allowances $\left(E(p_2^{CO2}) = (1 + \delta_{CO2}^e)\, p_1^{CO2} > p_1^{CO2}\right)$, it may be attractive for power firms to deviate from their hedging schedule and to contract greater volumes of coal $(c_1 > \gamma_1 * C)$ and gas $(g_1 > \gamma_1 * G)$ in year one. In this case the hedging demand for CO_2 allowances increases in year one and decreases in year two. Accordingly, if expectations of future carbon prices are below forward contracts for CO_2 allowances, the hedging demand for CO_2 allowances decreases in year one and increases in year two compared to the hedging schedule.

3.2. Aggregate hedging demand by power sector

The hedging model can be extended to quantify the aggregate CO_2 hedging demand by the power sector. Therefore, we need the average weighted hedging schedule of Western European power generators. Three power generators disclosed their hedging schedule in the annual report of 2010 (E.ON 2011; RWE 2011; Vattenfall 2011). Assuming the hedging schedule as suggested by Eurelectric (2009) for the remaining firms, we can calculate the average schedule to hedge power: 20% of power production three years ahead, 46% two years ahead, 84% one year ahead of production. Table 1 shows that the aggregate hedging demand for CO_2 allowances has been increasing for the last three years, since many power generators acquire their CO_2 allowances in auctions and do not longer receive them for free starting in 2013. This calculation excludes hedging demand from Eastern European utilities, since they will continue to receive free allowances.

Table 1: Aggregate hedging demand (yearly average in %)

Years j\i	2010	2011	2012	2013	2014	2015	2016
2013	20	46	84	0	0	0	0
2014	0	20	46	84	0	0	0
2015	0	0	20	46	84	0	0
2016	0	0	0	20	46	84	0
% of power hedged by year i for years j	20	66	150	150	150	150	150

Source: E.ON (2011), Eurelectric (2010), RWE (2011), Vattenfall (2011)

With this hedging schedule ($\gamma_1 = 20\%, \gamma_2 = 46\%, \gamma_3 = 84\%$), the model can be extended to four years $(i: 1,2,3,4)$ and to three generation technologies: coal C, gas G and non-fossils R. For hedgers it is attractive to deviate from their hedging schedule by acquiring more CO_2 forward contracts when their expectations of future carbon prices exceed forward contract prices or fewer, when their expectations are lower. To hedge power that they will produce in year four, they can buy forward contracts for CO_2 allowances at market rate three years ahead $\left(p_1^{CO2}(1+\delta_{CO2}^m)^4\right)$, they can wait one year and buy forward contracts two years ahead $\left(p_1^{CO2}(1+\delta_{CO2}^m)^3\,(1+\delta_{CO2}^e)^1\right)$, they can buy forward contracts one year ahead $\left(p_1^{CO2}(1+\delta_{CO2}^m)^2\,(1+\delta_{CO2}^e)^2\right)$, or they can buy forward contracts in the final year $\left(\mathrm{p}_1^{\mathrm{CO2}}(1+\delta_{\mathrm{CO2}}^{\mathrm{m}})^1\,(1+\delta_{\mathrm{CO2}}^{\mathrm{e}})^3\right)$. The Lagrangian can be formulated as:

$$\max_{c_1,g_1,r_1,c_2,g_2,r_2,c_3,g_3,r_3,\lambda_1,\lambda_2,\lambda_3} L = \max_{c_1,g_1,r_1,c_2,g_2,r_2,c_3,g_3,r_3,\lambda_1,\lambda_2,\lambda_3} (c_1+g_1+r_1)\,p_1^e\,(1+\delta_e^m)^4 + (c_2+g_2+r_2)\,p_1^e\,(1+\delta_e^m)^3(1+\delta_e^e)^1 + (c_3+g_3+r_3)\,p_1^e\,(1+\delta_e^m)^2(1+\delta_e^e)^2 + (C-c_1-c_2-c_3+G-g_1-g_2-g_3+R-r_1-r_2-r_3)\,p_1^e\,(1+\delta_e^m)^1(1+\delta_e^e)^3 \tag{20}$$

$$
\begin{aligned}
&-c_1\left(\frac{p_1^c}{f^c}(1+\delta_c^m)^4+i_{CO2}^c*p_1^{CO2}(1+\delta_{CO2}^m)^4\right)\\
&-c_2\left(\frac{p_1^c}{f^c}(1+\delta_c^m)^3(1+\delta_c^e)^1+i_{CO2}^c*p_1^{CO2}(1+\delta_{CO2}^m)^3\,(1+\delta_{CO2}^e)^1\right)\\
&-c_3\left(\frac{p_1^c}{f^c}(1+\delta_c^m)^2(1+\delta_c^e)^2+i_{CO2}^c*p_1^{CO2}(1+\delta_{CO2}^m)^2\,(1+\delta_{CO2}^e)^2\right)\\
&-(C-c_1-c_2-c_3)\left(\frac{p_1^c}{f^c}(1+\delta_c^m)^1(1+\delta_c^e)^3+i_{CO2}^c*p_1^{CO2}(1+\delta_{CO2}^m)^1\,(1+\delta_{CO2}^e)^3\right)\\
&-g_1\left(\frac{p_1^g}{f^g}\left(1+\delta_g^m\right)^4+i_{CO2}^g*p_1^{CO2}(1+\delta_{CO2}^m)^4\right)\\
&-g_2\left(\frac{p_1^g}{f^g}\left(1+\delta_g^m\right)^3\left(1+\delta_g^e\right)^1+i_{CO2}^g*p_1^{CO2}(1+\delta_{CO2}^m)^3\,(1+\delta_{CO2}^e)^1\right)\\
&-g_3\left(\frac{p_1^g}{f^g}\left(1+\delta_g^m\right)^2\left(1+\delta_g^e\right)^2+i_{CO2}^g*p_1^{CO2}(1+\delta_{CO2}^m)^2\,(1+\delta_{CO2}^e)^2\right)\\
&-(G-g_1-g_2-g_3)\left(\frac{p_1^g}{f^g}\left(1+\delta_g^m\right)^1\left(1+\delta_g^e\right)^3+i_{CO2}^g*p_1^{CO2}(1+\delta_{CO2}^m)^1\,(1+\delta_{CO2}^e)^3\right)\\
&-\alpha((\gamma_1*C-c_1)^2+(\gamma_2*C-c_1-c_2)^2+(\gamma_3*C-c_1-c_2-c_3)^2\\
&+(\gamma_1*G-g_1)^2+(\gamma_2*G-g_1-g_2)^2+(\gamma_3*G-g_1-g_2-g_3)^2+(\gamma_1*R-r_1)^2\\
&+(\gamma_2*R-r_1-r_2)^2+(\gamma_3*R-r_1-r_2-r_3)^2)\\
&+\lambda_1(C-c_1-c_2-c_3)+\lambda_2(G-g_1-g_2-g_3)+\lambda_3(R-r_1-r_2-r_3)
\end{aligned}
$$

Solving the extended hedging model, yields the following volumes for coal and gas:

$$c_1 \;=\frac{1}{2\alpha}*i_{CO2}^c*p_1^{CO2}(-(1+\delta_{CO2}^m)^4+(1+\delta_{CO2}^m)^3\,(1+\delta_{CO2}^e)^1)+\gamma_1*C \tag{21}$$

$$
\begin{aligned}
&c_2\\
&=\frac{1}{2\alpha}*i_{CO2}^c*p_1^{CO2}((1+\delta_{CO2}^m)^4-2(1+\delta_{CO2}^m)^3\,(1+\delta_{CO2}^e)^1+(1+\delta_{CO2}^m)^2\,(1+\delta_{CO2}^e)^2)\\
&-(\gamma_1-\gamma_2)\,C
\end{aligned}
\tag{22}
$$

$$
\begin{aligned}
&c_3\\
&=\frac{1}{2\alpha}*i_{CO2}^c\\
&*p_1^{CO2}((1+\delta_{CO2}^m)^3\,(1+\delta_{CO2}^e)^1-2(1+\delta_{CO2}^m)^2\,(1+\delta_{CO2}^e)^2+(1+\delta_{CO2}^m)^1\,(1+\delta_{CO2}^e)^3)+\frac{\lambda_1}{2\alpha}\\
&-(\gamma_2-\gamma_3)\,C
\end{aligned}
\tag{23}
$$

$$g_1 \;=\frac{1}{2\alpha}*i_{CO2}^g*p_1^{CO2}(-(1+\delta_{CO2}^m)^4+(1+\delta_{CO2}^m)^3\,(1+\delta_{CO2}^e)^1)+\gamma_1*G \tag{24}$$

$$
\begin{aligned}
&g_2\\
&=\frac{1}{2\alpha}*i_{CO2}^g*p_1^{CO2}((1+\delta_{CO2}^m)^4-2(1+\delta_{CO2}^m)^3\,(1+\delta_{CO2}^e)^1+(1+\delta_{CO2}^m)^2\,(1+\delta_{CO2}^e)^2)\\
&-(\gamma_1-\gamma_2)G
\end{aligned}
\tag{25}
$$

$$
\begin{aligned}
&g_3\\
&=\frac{1}{2\alpha}*i_{CO2}^g*p_1^{CO2}((1+\delta_{CO2}^m)^3\,(1+\delta_{CO2}^e)^1-2(1+\delta_{CO2}^m)^2\,(1+\delta_{CO2}^e)^2+(1+\delta_{CO2}^m)^1\,(1+\delta_{CO2}^e)^3)\\
&+\frac{\lambda_2}{2\alpha}-(\gamma_2-\gamma_3)G
\end{aligned}
\tag{26}
$$

The aggregate CO_2 hedging demand by the end of 2012 amounts to:

$$H = \left(3 * c_1 \ + 2 * c_2 \ + c_3 \right) i_{CO2}^{c} + \left(3 * g_1 \ + 2 * g_2 \ + g_3 \right) i_{CO2}^{g} \tag{27}$$

$$= \left(\frac{1}{2\alpha} * i_{CO2}^{c} * p_1^{CO2}(-(1+\delta_{CO2}^{m})^4 + (1+\delta_{CO2}^{m})^1 \ (1+\delta_{CO2}^{e})^3) + \frac{\lambda_1}{2\alpha} + (\gamma_1 + \gamma_2 + \gamma_3) \ C\right) i_{CO2}^{c}$$
$$+ \left(\frac{1}{2\alpha} * i_{CO2}^{g} * (-(1+\delta_{CO2}^{m})^4 + (1+\delta_{CO2}^{m})^1 \ (1+\delta_{CO2}^{e})^3) + \frac{\lambda_2}{2\alpha} + (\gamma_1 + \gamma_2 + \gamma_3) \ G\right) i_{CO2}^{g}$$

If expectation of future carbon price developments are the same as market rates of carbon forward contracts ($\delta_{CO2}^{m} = \delta_{CO2}^{e}$), equation (27) reduces to the hedging schedule $\left((\gamma_1 + \gamma_2 + \gamma_3) \ G * i_{CO2}^{g}\right)$. When expectations of future carbon prices are above forward contract price, the aggregate hedging exceeds the hedging schedule and when expectation are lower than market development, the aggregate hedging demand decrease below the hedging schedule.

4. Quantification of aggregate hedging demand

4.1. Parameterization

The parameters used to quantify the hedging demand in the power sector are summarized in Table 2. To calibrate the parameter α that introduces the quadratic term penalizing for deviations from the hedging schedule, we use information from the interviews. It was reported that 2 to 4 EUR difference in their carbon price expectation compared to market development are required to deviate from the hedging schedule. For example, $\alpha = 0.00000001012$ corresponds to a 10% increase in hedging demand for a 1 EUR increase in price expectation as compared to forward contract prices $\left(p_1^{CO2}(1+\delta_{CO2}^{e})^4 = p_1^{CO2}(1+\delta_{CO2}^{m})^4 + 1 \ EUR\right)$. The parameter α can be interpreted as transaction cost.

Table 2: Prices and parameter assumptions (for all scenarios)

Parameter	Unit	Value	Source
p_1^{CO2}	EUR/ t CO2	7.50	Point Carbon (2012)
α_1		0.00000001012	1 EUR, Δ10% hedging
p_1^{e}	EUR/MWh	51.40	
p_1^{c}	EUR/MWh	12.10	EEX (2012)
p_1^{g}	EUR/MWh	26.90	
C	MWh	677,064,475	2010 Annual Reports of 9 European utilities , Eurostat(2011)
G	MWh	537,001,275	
R	MWh	1,626,917,250	
i_{CO2}^{c}	t CO2/MWh	0.96	IPCC (2006)
i_{CO2}^{g}	t CO2/MWh	0.41	

f^c	%	40.80	IEA et al.(2010)
f^g	%	55.10	
γ_1	%	20	E.ON (2011), Eurelectric (2009), RWE (2011), Vattenfall (2011)
γ_2	%	46	
γ_3	%	84	

4.2. Results for aggregate hedging demand

We use three scenarios of carbon price expectations to assess their impact on aggregate hedging demand: In Scenario 1 future price are expected to develop at 0% instead of 5% as suggested by CO_2 forward contracts prices. In Scenario 2 future price expectation match forward contract prices ($\boldsymbol{\delta_{CO2}^m = \delta_{CO2}^e = 5\%}$). In scenario 3 future price expectation exceed forward contract prices. Thus the expected rate of CO_2 price development is 10% and the market rate is 5%.

The hedging model is formulated as a mixed complementarity model and programmed in GAMS. Table 3 summarizes the contracting volumes of coal, gas and non-fossils for three price development scenarios and the corresponding CO_2 hedging volumes. Thus, the CO_2 hedging volume three years ahead of production can range from 151 to 197 million t CO_2 depending on the differences of price expectations from forward contract prices. The volume of CO_2 allowances that are acquired in the final year can range from 114 to 160 million t CO_2. The aggregate CO_2 hedging demand ranges from 1.240 to 1.377 billion t CO_2 by the end of 2012.

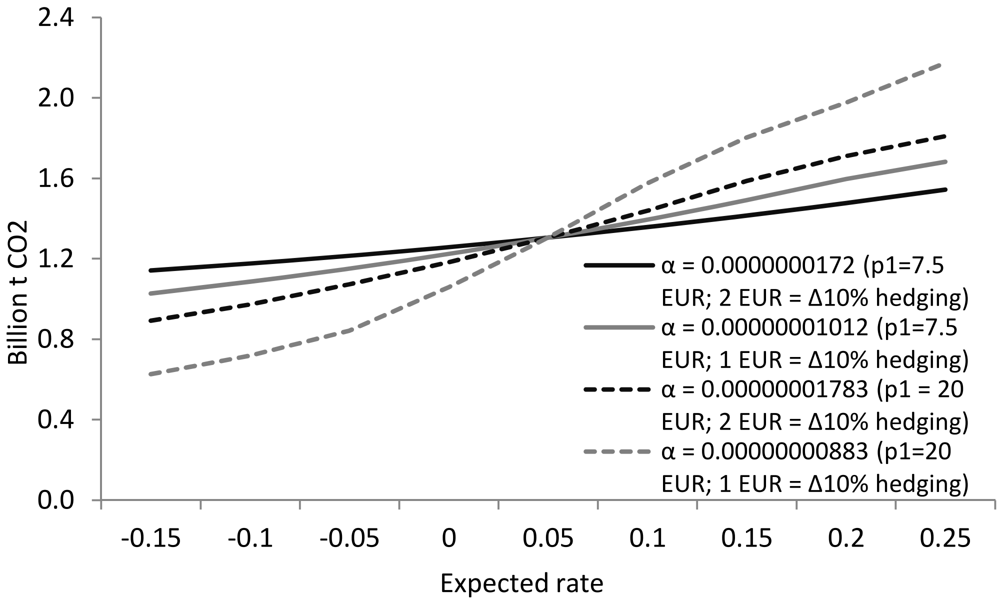
Table 3: Model results - Contracted volumes of coal, gas and non-fossils and CO_2 hedging

Variable	**Unit**	**Scenario 1** $\boldsymbol{\delta_{CO2}^m = 5\%, \delta_{CO2}^e = 0\%}$	**Scenario 2** $\boldsymbol{\delta_{CO2}^m = \delta_{CO2}^e = 5\%}$	**Scenario 3** $\boldsymbol{\delta_{CO2}^m = 5\%, \delta_{CO2}^e = 10\%}$
c_1	MWh	118,743,100	135,412,900	152,082,700
c_2	MWh	176,830,600	176,036,800	176,830,600
c_3	MWh	258,040,500	257,284,500	258,116,100
c_4	MWh	123,450,300	108,330,300	90,035,120
g_1	MWh	90,730,450	107,400,300	124,070,100
g_2	MWh	140,414,100	139,620,300	140,414,100
g_3	MWh	204,816,500	204,060,500	204,892,100
g_4	MWh	101,040,200	85,920,200	67,625,000
r_1	MWh	325,383,400	325,383,400	325,383,400
r_2	MWh	422,998,500	422,998,500	422,998,500
r_3	MWh	618,228,600	618,228,600	618,228,600
r_4	MWh	260,306,800	260,306,800	260,306,800
h_1	tCO2	151,192,900	174,030,500	196,868,100
h_2	tCO2	227,327,100	226,239,600	227,327,100
h_3	tCO2	331,693,600	330,657,900	331,797,200

h_4	tCO2	159,938,800	139,224,400	114,160,000
H	tCO2	1,239,926,000	1,305,229,000	1,377,056,000

Figure 3 shows the aggregate hedging demand at the end of 2012 for different expected discount rates and transaction cost parameters.

Figure 3: Aggregate CO_2 hedging volume as function of the expected rate



The results are consistent with economic intuition. If the expected price developments match carbon forward price development of 5%, the power companies follow the hedging schedule of 20% three years ahead, 46% two years ahead and 84% one year ahead of production. This corresponds to an aggregate hedging demand of 1.305 billion t CO_2 by the end of 2012. If price expectations exceed carbon forward contract prices at market rates, the CO_2 hedging demand increases beyond the hedging schedule in 2012. Similarly, if the price expectations are below carbon forward contract prices, hedging demand decreases below the hedging schedule. The lower companies' transaction cost, the higher their flexibility to adjust their hedging demand to their price expectations (black line). If we consider a current carbon price of 20 instead of 7.5 Euro/ t CO_2, a 10% increase in hedging volume for a 1 or 2 EUR increase in price expectation results in a greater deviation in the aggregate hedging demand (dotted lines).

5. Demand-supply balance

5.1. Model of CO_2 hedging, banking and net demand

To capture the interaction between the demand for CO_2 allowances from hedgers and speculators and the net demand, we expand the two-period hedging model. The net demand is composed of the volume of allowances that are allocated or auctioned within the EU ETS (Cap) plus the volume of imported offsets minus emissions. With increasing carbon prices, emissions decrease, fewer CO_2

allowances are needed and the surplus of CO_2 allowances increases. Thus, the net demand $Q_1^{net\ demand}$ can be formulated as upward-sloping linear curve for period one:

$$Q_1^{net\ demand} = \theta_1 + \beta * p_1^{CO2} \tag{28}$$

Accordingly, the net demand in period two is:

$$Q_2^{net\ demand} = \theta_2 + \beta * p_2^{CO2} \tag{29}$$

The unused allowances from period one can be banked for use in period two. Demand for these allowances derives from hedgers Q^h and speculators Q^s . The hedging demand is formulated as in equation (19):

$$Q_1^h = \left(\frac{1}{2\alpha} * i_{CO2}^c(E(p_2^{CO2}) - p_1^{CO2}) + \gamma * C\right) i_{CO2}^c + \left(\frac{1}{2\alpha} * i_{CO2}^g(E(p_2^{CO2}) - p_1^{CO2}) + \gamma * G\right) i_{CO2}^g \tag{30}$$

Speculators buy CO_2 allowances as open positions and thus bear the risk that CO_2 prices evolve differently than they expected. Speculators have an incentive to acquire CO_2 allowances $(Q^s \geq 0)$, if they expect carbon prices to increase at the discount rate exceeding their return requirements $(\delta_{CO2}^e \geq \delta_{CO2}^s)$. The discount rate refers to the growth rate between the forward contract price in period one and the expected carbon price in period two $\left(\delta_{CO2}^e = E\left(p_2^{CO2}\right)/p_1^{CO2} - 1\right)$. Thus the speculative demand can be formulated as maximum function:

$$Q_1^s = \max\left(\varphi\ \left(\frac{E(p_2^{CO2}) - p_1^{CO2}}{p_1^{CO2}} - \delta_{CO2}^s\right), 0\right) \tag{31}$$

The speculative demand increases with the expected carbon price in period two and decreases with the forward contract price in period one. The increase in the speculative demand depends also on the factor φ. For φ toward infinity it is assumed that an infinite volume of speculative demand is available at return rate δ_{CO2}^s.

Equations (30) and (31) form the aggregate demand in period one. Equalizing demand to the cumulative market surplus yields the equilibrium price. The market equilibrium in period one is:

$$\begin{aligned} & Q_1^{net\ demand} - Q_1^h - Q_1^s = 0 \\ & \Leftrightarrow \theta_1 + \beta * p_1^{CO2} - \left(\frac{1}{2\alpha} * i_{CO2}^c(E(p_2^{CO2}) - p_1^{CO2}) + \gamma * C\right) i_{CO2}^c \\ & - \left(\frac{1}{2\alpha} * i_{CO2}^g(E(p_2^{CO2}) - p_1^{CO2}) + \gamma * G\right) i_{CO2}^g - \max\left(\varphi\ \left(\frac{E(p_2^{CO2}) - p_1^{CO2}}{p_1^{CO2}} - \delta_{CO2}^s\right), 0\right) = 0 \end{aligned} \tag{32}$$

An increase in θ_1, for example an unexpected emission shortfall, triggers a price reduction in period one. This in turn triggers a combination of emission increase in period one and banking and hedging increase to period two.

In period two the net emission surplus and the volume of allowances transferred from period one through banking and hedging demand needs to be in balance. In the two-period model we ignore banking and hedging demand of allowances towards later periods:

$$\begin{aligned} & Q_2^{net\ demand} + Q_1^h + Q_1^s = 0 \\ & \Leftrightarrow \theta_2 + \beta * E(p_2^{CO2}) + \left(\frac{1}{2\alpha} * i_{CO2}^c (E(p_2^{CO2}) - p_1^{CO2}) + \gamma * C\right) i_{CO2}^c \\ & + \left(\frac{1}{2\alpha} * i_{CO2}^g (E(p_2^{CO2}) - p_1^{CO2}) + \gamma * G\right) i_{CO2}^g + \max\left(\varphi \left(\frac{E(p_2^{CO2}) - p_1^{CO2}}{p_1^{CO2}} - \delta_{CO2}^s\right), 0\right) = 0 \end{aligned} \quad (33)$$

Equilibrium in the case of no speculative demand

We first assume that speculative demand is zero, because $\frac{E(p_2^{CO2})-p_1^{CO2}}{p_1^{CO2}} < \delta_{CO2}^s$. Solving the market equilibrium in equation (32) for the price in period one yields:

$$p_1^{CO2} = \frac{-\theta_1 + \gamma\left(C * i_{CO2}^c + G * i_{CO2}^g\right) + E(p_2^{CO2}) \frac{[i_{CO2}^c]^2 + \left[i_{CO2}^g\right]^2}{2\alpha}}{\beta + \frac{[i_{CO2}^c]^2 + \left[i_{CO2}^g\right]^2}{2\alpha}} \quad (34)$$

Similarly, solving the market equilibrium in equation (33) for the price in period two yields:

$$E(p_2^{CO2}) = \frac{-\theta_2 - \gamma\left(C * i_{CO2}^c + G * i_{CO2}^g\right) + \frac{[i_{CO2}^c]^2 + \left[i_{CO2}^g\right]^2}{2\alpha} p_1^{CO2}}{\beta + \frac{[i_{CO2}^c]^2 + \left[i_{CO2}^g\right]^2}{2\alpha}} \quad (35)$$

Plugging in the equilibrium condition for period one in the equilibrium condition for period two, the price in period two $E\left(p_2^{CO2}\right)$ is:

$$E(p_2^{CO2}) = \frac{-\theta_2 * \beta - (\theta_1 + \theta_2) \frac{[i_{CO2}^c]^2 + \left[i_{CO2}^g\right]^2}{2\alpha} - \gamma * \beta\left(C * i_{CO2}^c + G * i_{CO2}^g\right)}{\left(\beta + \frac{[i_{CO2}^c]^2 + \left[i_{CO2}^g\right]^2}{2\alpha}\right)^2 - \left(\frac{[i_{CO2}^c]^2 + \left[i_{CO2}^g\right]^2}{2\alpha}\right)^2} \quad (36)$$

Accordingly, this leads to an equilibrium price in period one of:

$$p_1^{CO2} = \frac{-\theta_1 + \gamma\left(C * i_{CO2}^c + G * i_{CO2}^g\right)}{\beta + \frac{[i_{CO2}^c]^2 + \left[i_{CO2}^g\right]^2}{2\alpha}} + \frac{-\theta_2 * \beta - (\theta_1 + \theta_2)\frac{[i_{CO2}^c]^2 + \left[i_{CO2}^g\right]^2}{2\alpha} - \gamma * \beta\left(C * i_{CO2}^c + G * i_{CO2}^g\right)}{\left(\left(\beta + \frac{[i_{CO2}^c]^2 + \left[i_{CO2}^g\right]^2}{2\alpha}\right)^2 - \left(\frac{[i_{CO2}^c]^2 + \left[i_{CO2}^g\right]^2}{2\alpha}\right)^2\right)\left(\beta + \frac{[i_{CO2}^c]^2 + \left[i_{CO2}^g\right]^2}{2\alpha}\right)} * \frac{[i_{CO2}^c]^2 + \left[i_{CO2}^g\right]^2}{2\alpha} \tag{37}$$

In equilibrium the prices decrease with increasing surplus in period one (θ_1) and period two (θ_2) an the slope parameter β. If the hedging schedule increases in period one $\left(\gamma * C * i_{CO2}^c + \gamma * G * i_{CO2}^g\right)$ and adds to the surplus in period two, the price in period two decreases.

Equilibrium in the case of speculative demand

We now assume that banking volume from period one and therefore the price difference between the period increases to the level that speculative demand is attracted $\frac{\mathbf{E(p_2^{CO2})-p_1^{CO2}}}{\mathbf{p_1^{CO2}}} \geq \boldsymbol{\delta_{CO2}^s}$. To simplify the calculations we assume $\boldsymbol{\varphi} \to \infty$**.** If $\boldsymbol{Q_1^s}$ is not infinite, but a positive fixed number, then $\frac{\mathbf{E(p_2^{CO2})-p_1^{CO2}}}{\mathbf{p_1^{CO2}}} = \boldsymbol{\delta_{CO2}^s}$. Combining this with the allowance balance across the periods

$$\begin{aligned} &Q_1^{net\ demand} - Q_1^h - Q_1^s + Q_2^{net\ demand} + Q_1^h + Q_1^s = 0 \\ &\Leftrightarrow \theta_1 + \beta * p_1^{CO2} + \theta_2 + \beta * E(p_2^{CO2}) = 0 \end{aligned} \tag{38}$$

provides the equilibrium outcome

$$p_1^{CO2^*} = \frac{-(\theta_1 + \theta_2)}{\beta(2 + \delta_{CO2}^s)} \tag{39}$$

$$E(p_2^{CO2})^* = \frac{-(\theta_1 + \theta_2)(1 + \delta_{CO2}^s)}{\beta(2 + \delta_{CO2}^s)} \tag{40}$$

5.2. Quantification of CO2 hedging, banking and net demand

We consider two cases to assess the interaction of the CO_2 hedging demand in the power sector, CO_2 hedging demand in the power sector, CO_2 banking by speculative investors and CO_2 price dependent emission levels in a two-period model: in case one speculative investors do not expect their return requirements to be met and therefore do not acquire any allowances, in case two they have an incentive to bank and thus add to the demand for unused allowances.

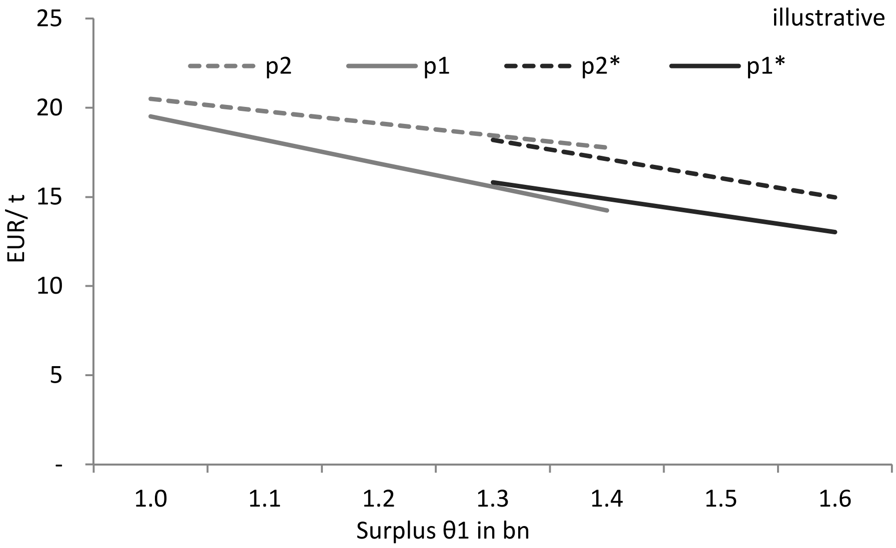
To illustrate the interactions with speculative investment and CO_2 price dependent emission levels, we use the parameters in Table 4.

Table 4: Parameter assumptions

Parameter	Unit	Value
θ_2	billion	3.0
β	billion	0.05
φ		∞
δ^s_{CO2}	%	15

The prices in market equilibrium depend on the net demand of CO_2 allowances available for banking. Figure 4 depicts price equilibriums for different surplus volumes in period one.

Figure 4: Price equilibriums for different surplus levels



An increase in the surplus in period one results in a decrease in the price in period one, but also in period two. With increasing surplus in period one, the price in period one decreases faster than the price in period two. This means that the discount rate has to increase with increasing surplus levels for the case of no speculative demand to achieve equilibrium. Once the discount rate is high enough so that speculative investors bank CO_2 allowances, the discount rate stabilizes at 15%. Thus the prices in period one are higher than without speculative demand. At the same time the speculative investment adds to the net demand in period two and thus lowers prices in period two.
This means that once the surplus exceeds the hedging demand, the price falls steeper with each additional tonne of CO_2.

6. Conclusion

CO_2 hedging by power generators can stabilize the demand-supply balance at lower discount rates than CO_2 banking by speculative investors, when hedging meets the net demand of CO_2 allowances in EU ETS.

First, we model the hedging demand for CO_2 allowances capturing the insights from interviews with 13 power generators. We find two main factors that determine the CO_2 hedging volume: First, the CO_2 hedging volume depends on the volume of power sold forward which is a corporate strategy decision but can be adjusted where forward prices deviate significantly from expectations within companies. Second, power generators can hedge with an emphasis on one specific generation technology when this is supported by attractive forward prices- both for carbon and for other fuels. According to our analysis the aggregate hedging demand will range from 1.2 to 1.4 billion t CO_2 by the end of 2012.

Second, we model the interactions of CO_2 hedging demand in the power sector, CO_2 banking by speculative investors and CO_2 price dependent emission levels in a two-period framework. Once the surplus is growing beyond the median hedging volume of 1.3 billion t CO_2 in the power sector, speculative investment is needed to balance the market. This implies that the price in period one decrease faster than the price in period two and the discount rate stabilizes at 15%. This points to the value of reducing the surplus of CO_2 allowances in EU ETS by about 1.3 billion t CO_2 to ensure hedging can make a significant contribution to stabilize carbon prices.

The EU Commission proposes back-loading CO_2 allowances auctions by 900 million t in 2013-2015 in order to respond to low carbon prices (European Commission 2012). The back-loading of CO_2 allowances to the end of phase three provides time for policymakers to implement structural reforms in order to create long term scarcity of CO_2 allowances in the EU ETS. Our analysis suggests that back-loading 900 CO_2 allowances will lead to a surplus of 400 to 600 million t CO_2 beyond hedging demand. This requires speculative investors to balance the market and implies high discounting of future price expectations.

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