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Free EUAs and fuel switching (good news: Santa Claus brought you carbon)

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Free EUAs and fuel switching (good news: Santa Claus brought you carbon)

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Abstract

We focus on the impact of EUAs to reduce emissions on the expected profit of an electricity producer. We show that grandfathering of EUAs introduces significant distortion in the system. It turns out that a producer can identify a threshold price of EUAs above which it is economically preferable to reduce production and sell the unused certificates. An empirical application (to an italian and german producers) shows that given the historical quotas of EUAs freely distributed (about 92%), EU ETS has represented probably more a gift to the owners of gas and coal plants, than an incentive to switch their plants to renewables.

Key words: emission markets, electricity production, renewable resources, EUA, green certificates
JELCS: Q40, Q42

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1 Introduction

Under the Kyoto Protocol the EU has committed to reduce GHG emissions by 8% compared to the 1990 level by the years 2008–2012. To this end, the European Union has adopted an European Union-wide Emission Trading Scheme (EU ETS) in order to reduce CO_2 emissions by companies from the energy and other carbon-intensive industries. The EU ETS envisaged several time phases. The first one, from 2005 to 2007, could be considered as a trial or "warm-up" period aimed at getting the scheme "up and running". The second allocation phase is planned for the period 2008–2012, which coincides with the Kyoto commitment period. From then on, consecutive five-year periods (starting from 2013–2017) would span the potential post-Kyoto commitment periods. Since the introduction of the EU ETS in 2005, CO_2 emission certificates are now available as a new financial instrument and are traded in a new market, the emission unit market. This market is the largest ever, since 11500 emission sources are considered versus 3000 of the SO_2 Market in USA. The emission certificates allow for the emission of one ton of CO_2 each and are called European Union Allowances (EUAs). The emission unit market aims at reducing environmental and production costs while respecting the Kyoto Protocol, allows to price the capacity of innovation on industrial sectors and since carbon allowances can also be traded over the counter, with its function of price discovery it gives information on the permit trade as a whole. Even though CO_2 is seen here as a commodity, traded in an organized market, what is actually sold is a lack or absence of the gas in question. Sellers of the allowances are expected to produce fewer emissions than they are allowed to, so they may sell their extra allowances to industries that emit more than they are endowed to. Thus, the emissions are more a liability for the obligation to deliver the allowances to cover their emissions. Generally, a company's stock of emission allowances determines the degree of allowed plant utilization. Thus, a lack of allowances requires from the company either some plant-specific or process improvements, a cut or shutdown of the emission producing plant or the purchase of additional allowances and emission credits (Benz and Trück, 2009). Emissions trading is seen as a market-based and efficient instrument of environmental policy favoured by many economists and politicians, while EU firms now face a carbon-constrained reality in form of legally binding emission targets (Abadie and Chamorro, 2008).

The system regulates an annual allocation of the allowances. The emission budget a country can allocate is given by the EU Burden Sharing Agreement which reassigns the aggregate EU Kyoto target among member States. At the beginning of each period, each country has to present a National Allocation Plant which defines how many emissions allowances each (major) emitter will get in this period. For all emissions produced each year, an industry must have the corresponding allowances by March 31 of the following year. Therefore, they can decide whether to abate emissions in-house or to buy allowances on the market. The trading system started operating officially on January 1st 2005. In the Phase I, like in other emission trading mechanisms, such as the SO_2 market, allowances were generously grandfathered, i.e. distributed for free, to polluting industries based on historical firm data on emission or fuel use (Jaehn and Letmathe, 2010). The same procedure applies in Phase II in reduced from. According to Böhringer and Lange (2005) and Bode (2006), in its initial stage grandfathering has been a necessary condition for the ETS to be accepted by carbon-intensive industries. The aim was essentially to assist enterprises, especially in the energy sector, or for which energy use and its management was a crucial part of their activity, to incorporate in their business plans the impacts of the Directive in an informed and rational manner (Georgopoulou et al., 2006). In this respect grandfathering is seen as a form of subsidizing in environmental policy making. Subsidizing is an (often efficient) instrument to achieve certain objectives, i.e. in this case to make the emission market work smoothly and, in the medium term, to stimulate investments in abatement technologies and to foster the use of clean inputs if pollution is unobservable (Arguedas and Van Soest, 2009). As an example of successful subsidizing we quote the use of subsidies to stimulate investment in renewable technologies (Falbo et al., 2008). On the other hand, other studies as well as models, consistently show that the energy industry, especially with a high number of allowances and a modern technology mix, has profited from emissions due to the consequent increase of electricity prices and at the cost of more downstream industries and private consumers (Bode, 2006; Lee et al., 2008; Jaehn and Letmathe, 2010).

The aim of this paper is twofold: first, while we do not question on the mechanism or the rationale behind the emission market, we will show that the market of emission allowances introduces a significant distortion to the economic conditions to produce. We show that it is possible to identify a threshold price for CO_2 allowances, above which production is not profitable; rather a producer prefers to sell his unused allowances. This is confirmed empirically by evidence on historical data from Germany and Italy. We consider the case of a (German and Italian) electricity producer, confronting the decision to invest in three different plants, two polluting (fed by coal and gas) and one renewable (wind), to take possibly advantage of Green Certificates. While under grandfathering switching to renewable or less polluting technologies is not convenient, without grandfathering we find a threshold carbon price, such as for prices above/below which the producer will choose renewables or will stick to the polluting technologies. Nevertheless, within the Integrated Risk Management framework (Falbo et al., 2010), the optimal policy for the producer will be to detain a portfolio of technologies. We observe that the two countries considered give different results, that is the German producer will find it profitable investing in renewables in presence of carbon prices which are lower than for the Italian one. This is due to the high differential of electricity prices between the two countries.

2 The Model

First of all, we analyze the profit function of an electricity producer, that is the case where all his capacity installed (Q) is composed by thermal plants of the same kind, so that unit production costs are uniform over his factories. Later we will consider a producer with diversified plants. Suppose that he receives for free a number of emission permits equal to αQ, that is a fixed percentage of his production capacity. Let p be the unit price of electricity (per MWh). Assuming a linear productivity function, to generate 1 MWh of energy his plants require an amount equal to c of variable costs (mainly represented by fuel) and emit an amount equal to k tons of CO_2 (or CO_2 equivalent greenhouse gases).

As a consequence of the cited European directive, all the emissions must be "covered" by a corresponding number of EUA, so for every unit of energy the producer will have to buy a quantity of emission allowances equal to $(1-\alpha)\ k$. The price of an emission certificate (p_A) is quoted daily on the market. We assume here that at a macro-economic level there is not influence of p_A on p, which can be debatable in the electricity sector where the degree of competition is low. However such an assumption can be acceptable as long as some frictions exist in transferring the variations of production costs to sale price, at least when the price changes are relatively small. Besides, the following analysis is interesting in that it points to some relevant conclusions to the governance of the energy sector and with respect to the objectives of the European directive on the emissions in the atmosphere.

Depending on the economic conditions faced daily, the producer can decide if it is convenient to activate his plants or not. We assume that turning the plant on and off is costless. To define his profit function we therefore distinguish two cases. If he decides to activate the plants the unit profit function is:

$$p - c - (1-\alpha)\ k\, p_A - c_m$$

where c_m are the unit fixed costs (i.e. operation and maintenance). If he decides to keep his plants turned off, he can sell the unused certificates and its unit profit function is

$$\alpha\, k\, p_A - c_m$$

The decision to activate or not the plants can therefore be reduced to:

$$p - c - (1-\alpha)\ k\, p_A > \alpha\, k\, p_A$$

that is:

$$p > c + k\,p_A \tag{1}$$

Such a decision rule is nothing but a specification of what is called a "clean spark spread" option (in the particular case of an electricity producer using gas plants, or "clean dark spread" in the case of coal), that is the option to start production only when it is profitable (Falbo et al., 2010). Notice that such a decision is not affected by the level of α. With respect to the classical formulation, the term $k\,p_A$ introduces a specific analysis of the impact at a micro-economic level of the EUA system. From (1) we observe that, since $k\,p_A$ is positive, the plant will be kept shut off more often than in the absence of an EUA market. To this purpose consider the gross profit (G) function:

$$\begin{aligned} G &= \begin{cases} Q\ (p - c - (1-\alpha)\ k\,p_A - c_m) & \text{if } p > c + k\,p_A \\ Q\ (\alpha\,k\,p_A - c_m) & \text{if } p \leq c + k\,p_A \end{cases} \\ &= Q\ (\alpha\,k\,p_A + \max(p - c - k\,p_A; 0) - c_m) \end{aligned}$$

In the specification of gross profit observe the typical payoff of the mentioned call option on the (spark/dark) spread $p - c$ corrected by the effect of carbon price. Taking the expectations we have:

$$E[G] = Q\ (\alpha\,k\,p_A + E[\max(p - c - k\,p_A; 0)] - c_m) \tag{2}$$

If we analyze the derivative of $E[G]$ with respect to p_A we discover (see the Appendix) that it is not always negative, as it could be expected:

$$\frac{dE[G]}{dp_A} = Q\,k\ (\alpha - P[p > c + k\,p_A]) \tag{3}$$

where $P[\cdot]$ is the probability of event $\cdot$. We do not need to specify a particular form for P, for the purposes of this analysis. It suffices to assume that is continuous in its arguments. The event considered in (3) coincides with that in (1), that is the economic condition required to activate or to turn the production plants off. For the profit function to have economic consistency (i.e. to decrease if a cost increases) it is therefore required that $\alpha - P[p > c + k\,p_A] \leq 0$. Let p_A^* the price of emission certificates such that $\alpha - P[p > c + k\,p_A^*] = 0$. As shown in figure (1), p_A^* is the point of minimum for 2, so that $\alpha - P[p > c + k\,p_A] \geq 0$, whenever $p_A \geq p_A^*$. In such a case ($p_A > p_A^*$) production will be at a rate lower than α, so that the producer will be able to sell on the market the exceeding allowances. If on the contrary $p_A < p_A^*$, he will have to buy the necessary allowances in the market and will make profits producing electricity. The expected profit function is limited from below by the line $Q\ (k\,\alpha\,p_A - c_m)$ which represents the profits generated by only selling the EUAs to market (i.e. no

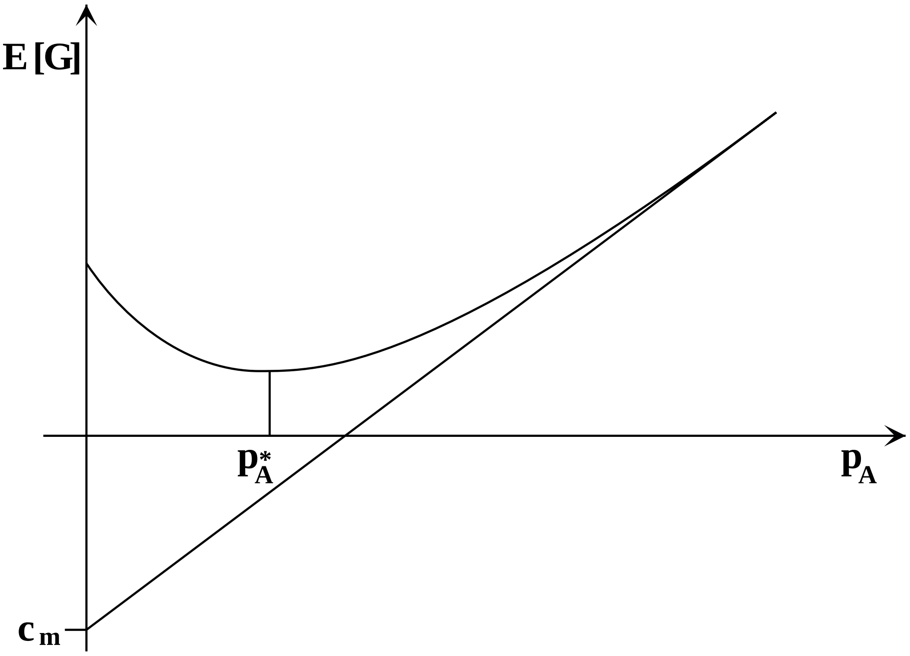


Fig. 1. Expected profit as a function of p_A.

production). The expected profit function is asymptotic to such a line: the higher p_A the lower the probability of turning the plants on.

Notice that p_A^* is an individual parameter, since it depends on the pollution coefficient (k) of each producer. Some relevant economic distortions happen if such consistency is violated, which is a case when some of the following circumstances are verified singularly or, more realistically, concurrently:

- the producer is a big polluter (high values of k)
- the unit costs c are very high;
- the quota α of the certificates distributed for free is high;
- the level of p_A is very high;
- the current price of energy is low.

The first two conditions depend largely on the technology adopted by the producer, so they can be considered together; the last three ones are market driven and have some degree of independence. We comment the following cases.

(1) If p_A is greater than p_A^*, the producer will have an incentive to stop production and profit from the sale of his unused certificates; therefore in this case he will even take advantage of higher levels of p_A.
(2) If the producer has an expensive and polluting technology, p_A^* is lower, all other things equal. This can be easily seen. In Equation (3) let $b = k\,p_A^*$ the value such that $P\,[p > c + b] = \alpha$, with c constant. Under quite general conditions P is clearly monotonically decreasing with respect to

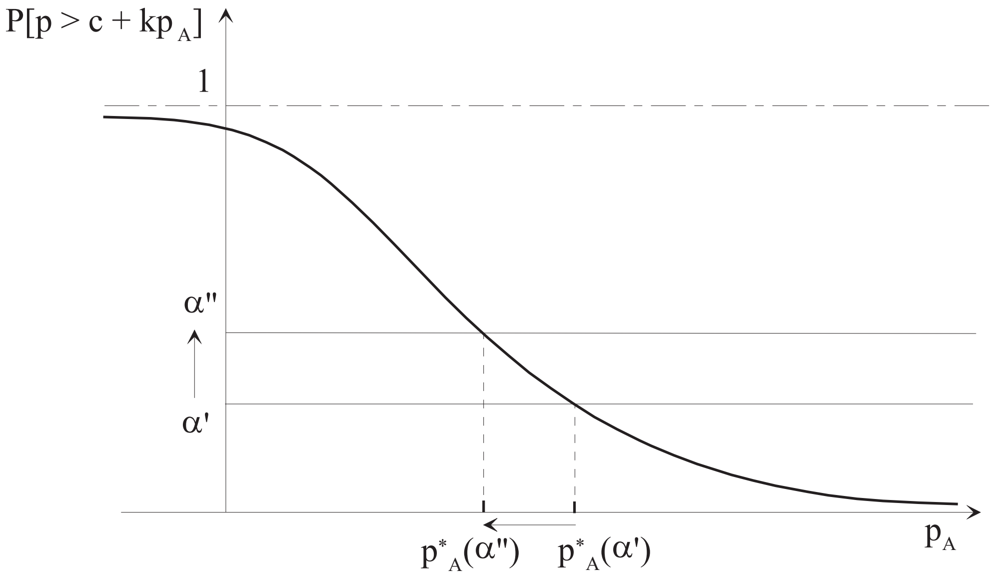


Fig. 2. Increasing the value of α reduces p^*_A.

b, so we can write $b = P^{-1}(\alpha; p, c)$, that is b can be seen as the allowance cost to emit CO_2 per every MWh of energy produced which minimizes his expected profit. Then:

$$k\, p^*_A = P^{-1}(\alpha; p, c) \Longrightarrow p^*_A = \frac{P^{-1}(\alpha; p, c)}{k} \tag{4}$$

Equation (4) clearly shows the inverse relation between p^*_A and k. The practical consequence of this evidence is that comparing two producers (i, j) with different CO_2 emission intensities ($k_i < k_j$): there will be an interval $\left(p^*_{A,j}, p^*_{A,i}\right)$ where producer j (the more intensive CO_2 emitter) will enjoy increasing allowance prices of CO_2, while producer i will suffer. The environmental incentive to reduce parameter k is totally subverted in this region.

(3) higher levels of α generate the same distortion. Increasing the quantity of allowances in the market (i.e. α) lowers the value of p^*_A, since more unused allowances are available for sale. Figure (2) shows the origin of the negative dependence between α and p^*_A.

This discussion shows that the intended objective of reducing emission of CO_2 in the sector of electricity production through the creation of the EUA market, at least during the grandfathering phase, can be largely vanished under quite normal circumstances. Among these, the large portion of certificates which are freely distributed is history. The analysis confirms the common belief that the EUA distributed for free to the electicity industry have not contributed to the renewal of the most CO_2 intensive plants, rather they have generated free profits for the pocket of the electricity generators which are endowed with a large portion of those plants.

2.1 Incentives to production of electricity through renewable energy resources and fixed costs

While EUAs are supposed to be a penalty for emitting CO_2 in the atmosphere, Green Certificates are incentives to promote electricity production through renewable resources plants (RES-E). The inclusion of Green Certificates to the equation of profits has either a positive (negative) impact depending if a producer meets (does not meet) an established minimal percentage target through his RES-E production. Green Certificates, each of which is worth 1 MWh, may be purchased or sold in the Green Certificates Market by parties with deficits or surpluses of generation from renewables. The hourly profit, per MW of capacity installed, of a fossil fuel producer can be set as:

$$G = \alpha\, k\, p_A + \max\left[p - c - k\, p_A - \alpha_{GC}\, p_{GC}; 0\right] - c_m$$

where p_{GC} is the unit price of a Green Certificate, α_{GC} is the Green Certificate percentage target. The equation shows that the Green Certificates program amounts to a cost proportional to production. For a producer based on RES-E plants only, the hourly profit, per MW of capacity installed, is:

$$G = \gamma\ (p + p_{GC}) - c_m$$

where γ is the efficiency parameter of the plant.

A producer adopting RES-E plants could apply in a project for CO_2 reduction, in which case he could receive a certain quota of CERs (similar to EUAs). However he then should give up any other form of incentivation. This is usually very unfavorable, so we neglect this opportunity and assume that the incentivation of renewables is supplied only by Green Certificates.

3 An application to the decision of switching plants from polluting to renewable

As an empirical application and a refinement of the previous model, we now consider an electricity producer evaluating the expected profits resulting from an investment in a combination of three types of plants: carbon, gas and wind.

In the following analysis we have compared two different markets in the year 2006: the Italian and the German market, besides in the Italian case we have considered a small wind park, while for the German case we have used the whole wind production of a big company (EON), so that the intermittence of the Italian wind plant is clearly higher. However the average activity (hours/year) is actually the same $\sim 19\%$.

	$c_{mg} = \; 4 \;$ €/h	$k_g = \; 0.40392$
$\Phi_c = \; \frac{1000 \text{ €/kW}}{1200 \text{ €/kW}} = \frac{5}{6}$	$c_{mc} = \; 4 \;$ €/h	$k_c = \; 1.36224$
$\Phi_w = \; \frac{1000 \text{ €/kW}}{1500 \text{ €/kW}} = \frac{2}{3}$	$c_{mw} = \; 3.5 \;$ €/h	

Table 1
Parameters of the model.

The ICE one day forward price has been used for the gas cost, while the ARA index has been used for the coal cost (source: Datastream).

Both prices have been converted into €/MWh assuming an efficiency of 50% for the gas plant and 25% for the coal plant.

The other parameters of the model are reported in Table (1).

Italian law fixes a quota $\alpha_{GC} = 2\% + 0.35\%$ (year $-$ 2004) of renewables, that is $\alpha_{GC} = 2.7\%$ for 2006. The same quota has been used for the German case, which is "as if", since the incentives for the wind generation are not supplied by green certificates. German producers receive another form of incentive (i.e. feed-in tariffs), which favors RES-E plants but does not directly penalizes fossil fuel plants (Falbo et al., 2008). All other things equal, replacing the current incentives instead of our "as if" analysis would possibly shift the results towards a larger preference of coal plants than we obtained.

3.1 Risk neutrality case

We will consider first a decision based on expected profits, that is under a risk neutrality setting. To keep the initial investment constant among the three alternatives, the producer can scale down the capacity of each plant. In other words we assume that the cost of a plant depends linearly on its capacity (in MW). Taking the investment required to install a gas plant with 1 MW of capacity as the reference, we have that:

$$1_g \,\text{MW} = \Phi_c \,\text{MW} = \Phi_w \,\text{MW}$$

where Φ_c and Φ_w are respectively the conversion factors to express the capacities of a carbon and a wind plants which can be acquired with the same amount of money in alternative to a gas plant with 1 MW capacity.

Next to the different capacities which can be acquired with a given initial investment, the hourly profit generated through the three kind of plants will also differ depending on the costs of fuel, the intensity of the CO_2 emission and the costs of maintenance. In particular, keeping fixed the cost of 1 MW gas plant as the initial investment, we can write the following expressions for the hourly profit generated by the three choices:

$$\begin{aligned} G_g &= \alpha\, k_g\, p_A + \max\left[p - c_g - k_g\, p_A - \alpha_{GC}\, p_{GC}; 0\right] - c_{mg} \\ G_c &= \Phi_c\, \left(\alpha\, k_c\, p_A + \max\left[p - c_c - k_c\, p_A - \alpha_{GC}\, p_{GC}; 0\right] - c_{mc}\right) \\ G_w &= \Phi_w\, \left(\gamma\, \left(p + p_{GC}\right) - c_{mw}\right) \end{aligned} \tag{5}$$

where:

- G_g, G_c and G_w are respectively the profits of the gas, carbon and wind plant,
- k_g and k_c are respectively the emission intensities of the gas plant and the carbon plant,
- α_{GC} is the mandatory quota for renewable production defined through the Green Certificate program,
- p_{GC} is the price of a Green Certificate,
- c_{mg}, c_{mc} and c_{mw} are respectively the unit costs of maintenance (per MW) of the gas, carbon and wind plant,
- γ is the *efficiency* of the wind plant (related to the wind speed).

The problem of optimally diversifying an investment based uniquely on the expected values of profits is linear, so the solution is of the ”bang-bang” type, that is: it consists in placing all the investment in the single alternative offering the higher expected profit.

Figure (3) shows some contour plots of the expected profits versus p_A and p_{GC} for different values of α (the assigned quota of EUA) for the two producers. Darker areas are related to lower profits. The three colors (yellow, red and green) represent the most profitable technology (gas, coal and wind).

For increasing values of p_{GC} the expected profit of the wind plant (linearly) increases, while the profits of the fuel plants decrease because the increased production cost reduces not only the absolute value of the profits, but also the probability to have the plant turned on.

The impact of p_A is different: the profit of the wind plant does not depend on p_A, but the profits of the fuel plants change in the non-monotonic way described above. Increasing p_A the probability for the fuel plant to be turned on decreases. At the same time the profit from selling unused EUAs increases as well. For large values of p_A production is strongly reduced and consequently a great profit from the sale of the redundant EUAs occurs (except in the case $\alpha = 0$). The gas and the coal plants have different profit functions (because the distributions of the fuel costs differ and $k_g \neq k_c$).

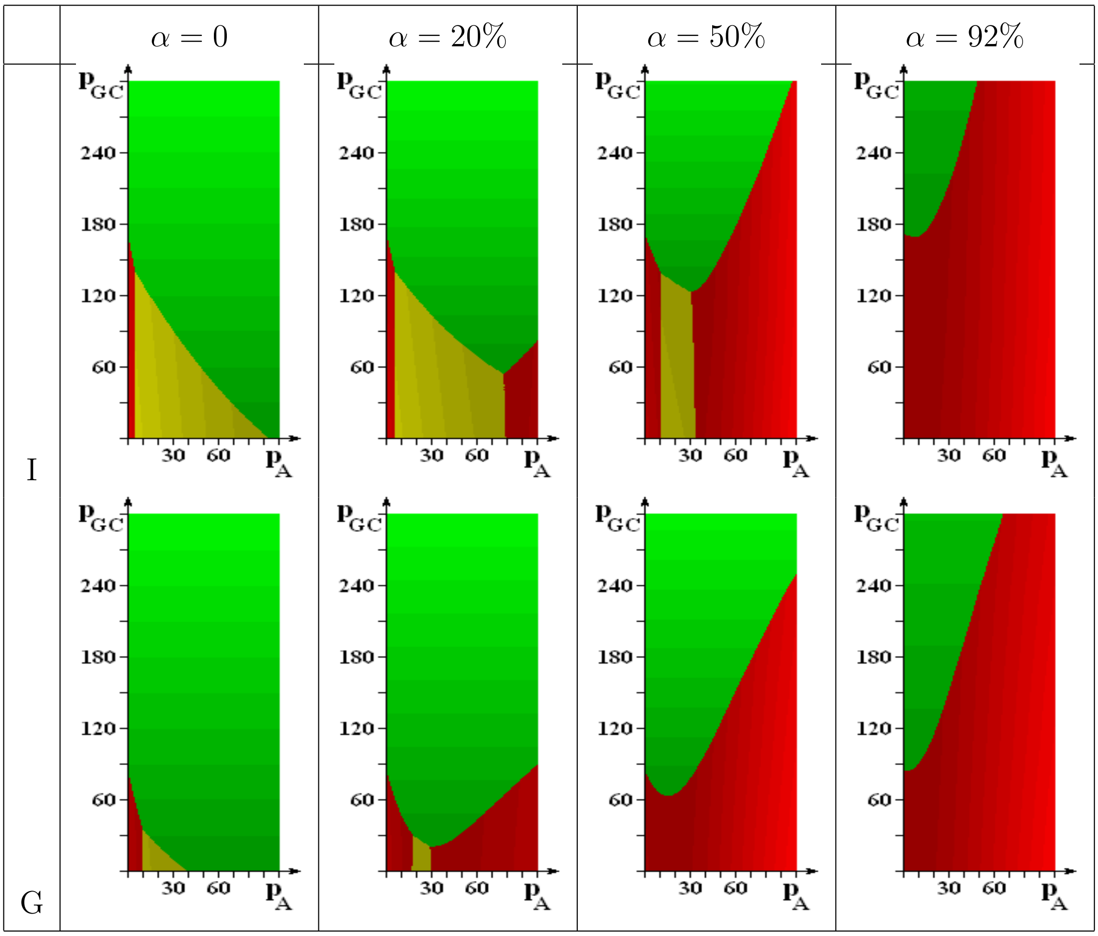


Fig. 3. Expected profits vs p_A and p_{GC} for several values of α, in the Italian market (I) and in the German market (G). Darker areas represent lower profits. The color shows the most profitable technology: gas is yellow, coal is red, wind is green.

The boundaries of the different areas represent pairs (p_A, p_{GC}) making indifferent the choice between the technologies.

It can be observed that, both for the Italian and the German producers, increasing α (i.e. the number of EUA freely distributed) has the effect of reducing the preference for the wind plants: the green area reduces passing from $\alpha = 0$ to $\alpha = 92\%$. At the same it can be noticed that coal plants become preferable to gas plants. In our case this result is a consequence of the (relatively) higher amount of EUAs distributed to coal plants. This trend reinforces when p_A is large.

In general the German producer finds wind plants economically preferable than it is for the Italian producer. This is mainly explained by the price of electricity which is lower in Germany than in Italy. This in turn makes gas and coal production too expensive for the German producer and lets wind plants the residual opportunity to generate profits.

	Italy	Germany
p_A	4.63 €/MWh	9.91 €/MWh
p_{GC}	140.05 €/MWh	34.73 €/MWh
$E\left[G\right]$	26.22 €/MWh	7.83 €/MWh

Table 2
Indifference pairs (p_A, p_{GC}) and expected profits for the Italian and German cases.

It is finally worth to observe that in some cases, it is possible to identify more pairs (p_A, p_{GC}) where the three technologies generate the same expected profit. In particular, they are the solution of the following equations in p_A and p_{GC}:

$$E\left[G_g\left(p_A, p_{GC}\right)\right] = E\left[G_c\left(p_A, p_{GC}\right)\right] = E\left[G_w\left(p_{GC}\right)\right] \tag{6}$$

Such findings are of primary importance to understand if the historical and the current prices of the EUAs are sufficient to promote a consistent shift of the future investments towards renewable resources plants.

The indifference prices for the incentives in the case $\alpha = 0$ are reported in Table (2)

Table (2) clearly shows the different situation of the two markets. Since wind production is significantly higher in Germany than in Italy, the German electricity price is lower (the average electricity price is 74.75 €/MWh in Italy versus 50.79 €/MWh in Germany). This in turn reduces the economic advantage of fuel fossil plants, so the indifference p_{GC} of Germany can be much lower. Since p_{GC} and p_A are substitute one of the other to keep the same level of expected profit, we have that the indifference price of EUAs in Italy is lower than in Germany. Finally we observe that there is a clear difference of the mark-up between the two countries.

The equilibrium wind/fuels is mainly affected by p_{GC}, while p_A drives the equilibrium gas/coal. This can be seen observing the partial derivatives of the expected profits with respect to the prices of the incentives, which determine the sensitivities of the profit:

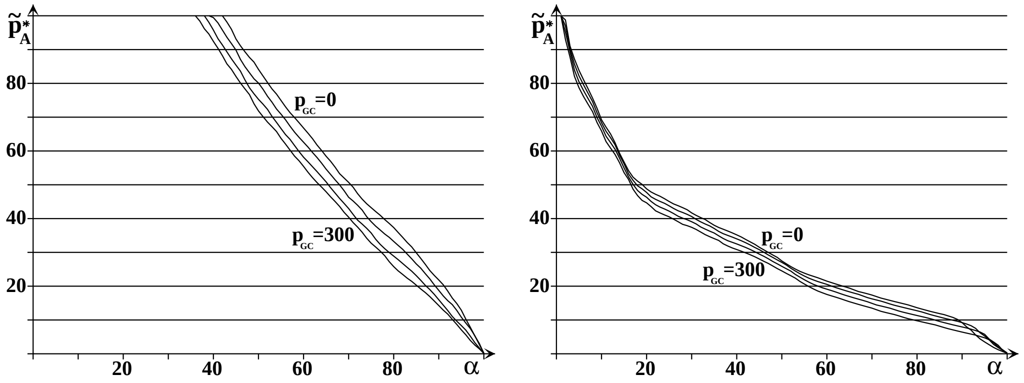
$$\begin{pmatrix} \partial_{p_A} E\left[G_g\right] \\ \partial_{p_{GC}} E\left[G_g\right] \end{pmatrix} = \begin{pmatrix} k_g \, \left(\alpha - P\left[p > c_g + k_g\, p_A + \alpha_{GC}\, p_{GC}\right]\right) \\ -\alpha_{GC}\, P\left[p > c_g + k_g\, p_A + \alpha_{GC}\, p_{GC}\right] \end{pmatrix}$$
$$\begin{pmatrix} \partial_{p_A} E\left[G_c\right] \\ \partial_{p_{GC}} E\left[G_c\right] \end{pmatrix} = \begin{pmatrix} \Phi_c\, k_c \, \left(\alpha - P\left[p > c_c + k_c\, p_A + \alpha_{GC}\, p_{GC}\right]\right) \\ -\Phi_c\, \alpha_{GC}\, P\left[p > c_c + k_c\, p_A + \alpha_{GC}\, p_{GC}\right] \end{pmatrix}$$
$$\begin{pmatrix} \partial_{p_A} E\left[G_w\right] \\ \partial_{p_{GC}} E\left[G_w\right] \end{pmatrix} = \begin{pmatrix} 0 \\ \Phi_w\, E\left[\gamma\right] \end{pmatrix}$$

In the case $\alpha = 0$, for conventional fuels we have $\frac{\partial_{p_A} E[G]}{\partial_{p_{GC}} E[G]} = \frac{k}{\alpha_{GC}}$. This ratio is about 14.26 for gas and 50.45 for coal, so the expected profit is significantly more sensible with respect to p_A rather than p_{GC}. This fact remains true also when $\alpha \neq 0$, unless

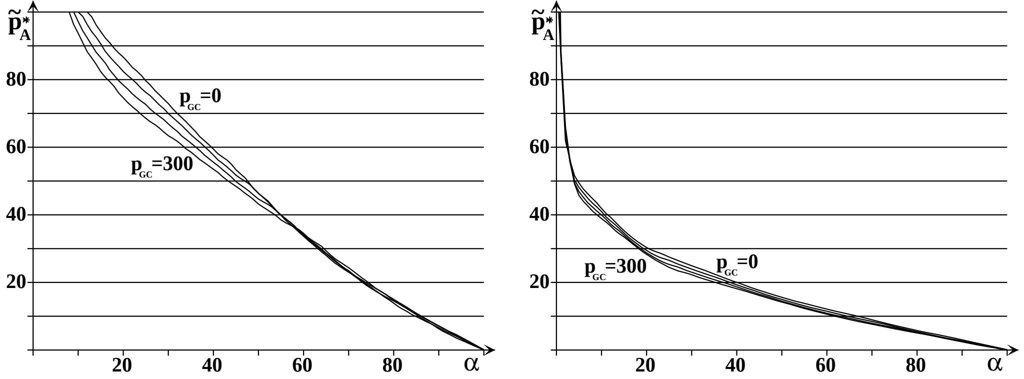
$$\alpha \sim \left(1 + \frac{\alpha_{GC}}{k}\right) P\left[p > c + k\, p_A + \alpha_{GC}\, p_{GC}\right] \sim P\left[p > c + k\, p_A + \alpha_{GC}\, p_{GC}\right] \tag{7}$$

This condition holds when α is close to the probability of activating the plants. In turn such a condition holds when $p_A \sim p_A^* - \frac{\alpha_{GC}}{k}\, p_{GC}$, that is when p_A minimizes the expected profit of the fuel plant. It is interesting to observe the differences between the potential effect of the two types of incentives (i.e. EUA and Green Certificates). The derivative of the expected profit with respect to the price of Green Certificates is always negative, as it is expected from an economic point of view. On the contrary the corresponding derivative with respect to the price of EUAs can even get positive, especially if the level of α is close to 1. The presence of the additional cost of Green Certificates in the expected profit function has the effect of further lowering the probability P, that is to increase the chances of spoil the mechanics of the EUAs.

Figure (4) shows the EUA price of minimal expected profit for gas and coal plants in Germany and Italy as a function of α for different values of p_{GC}. Such a price is clearly negatively related to α, since larger quotas of EUAs increase the expected profit of selling them. In other words the theoretical results discussed in section are confirmed even in the presence of Green Certificates. Observing how the four graphs ($p_{GC} = 0, 100, 200, 300$) remain basically unchanged in different cases, we can conclude indeed that Green Certificates play a negligible role.



Italian market, gas plant   Italian market, coal plant



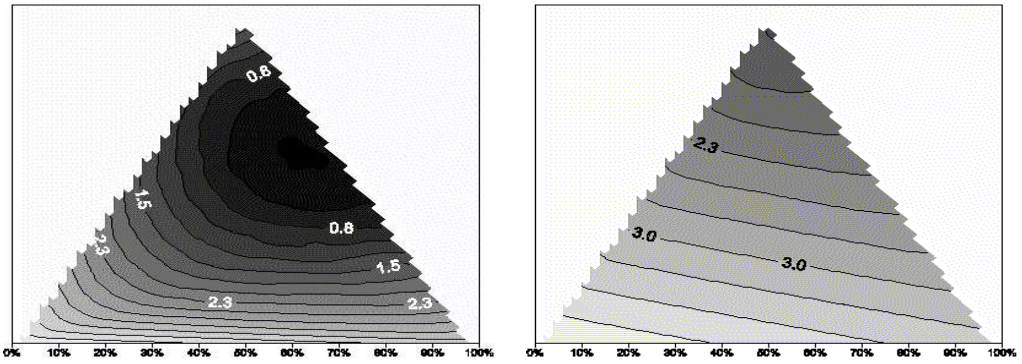
German market, gas plant   German market, coal plant

Fig. 4. p_A^* (in €/MWh) as a function of the assigned percentage α of EUAs for different values of p_{GC}: 0, 100, 200, 300 €/MWh.

3.2 Risk aversion case

Let us now introduce some considerations about risk management. The three kind of plants have diverse opportunities to halt production and different cost volatilities. Fixing p_A and p_{GC} so that the expected profit for the three alternative plants are equal, we now measure the risk connected to a productive mix. Figure (3.2) shows the $\text{VaR}_{95\%}$ (Value at Risk of the losses at the 95-th percentile) for different portfolios of the three technologies: the top vertex represents a producer investing uniquely in wind plants, the bottom-left vertex is the case of investing only in gas plants and the bottom-right vertex in coal plants. All other points inside the triangle can be univocally associated to a combination of the three technologies.

The two panels represent respectively the case of the two producers located in Italy and Germany. The VaR varies from 0.3 €/MWh up to 4 €/MWh for the Italian producer, from 1.5 €/MWh up to 4 €/MWh for the German producer. It is interesting to observe that the wind plant is the least risky solution in Germany, probably because thermal plants are often turned off as a consequence of the lower electricity prices. For the Italian case a mix



(A) (B)

Fig. 5. $\mathrm{VaR}_{95\%}$ plot for the Italian (A) and the German (B) markets. The darker area is related to lower risk.

coal-wind (about 35% coal and 65% wind) is optimal with a negligible gas percentage. The reason is that gas price is much more volatile than coal and, with respect to the wind component, the small park of the Italian producer makes its electricity production too irregular to suggest a 100% wind plant.

4 Conclusions

The paper contributes to the discussion and the criticism against the grandfathering of EUAs.

We analyze the expected profits of an electricity producer and find an individual threshold value for the EUAs price over which he will be able to increase his profits by reducing production and selling the unused certificates. As a consequence the expected effect of the EUA system vanishes, as since he will find not profitable converting his plants towards technologies with low or no-emission.

Such theoretical results are reinforced through an empirical application based on current data of production and market prices. In particular we applied our model to the case of two electricity producers (price takers), respectively located in Italy and Germany. What is particularly striking is that the high quotas of free allowances (about 92% in phase 1 and 2 of EU ETS) have more probably generated a shift from clean production (wind) to the most polluting production, i.e. coal, than viceversa. This is true both in the case of Germany, where a significant portion of electricity is generated by renewables, and of Italy, where renewables are still low.

Appendix

4.1 Proof of equation 3

An intuitive proof of equation 3 is illustrated here. So the probability measure of (p, c) is assumed to be absolutely continuous with respect to Lebesgue measure on $\mathbb{R}^2$ and its Radon-Nikodym derivative $\rho\,(p, c)$ is a function regular enough to allow the derivative and the integral operators to commute (step 4) and the use of Leibniz integral rule (step 5)

$$
\begin{aligned}
&\partial_{p_A} E\,[G] = \\
&\overset{(1)}{=} \partial_{p_A} \int_0^{+\infty} dc \int_0^{+\infty} \left(Q\ \left(\alpha\, k\, p_A + \max\,[p - c - k\, p_A; 0] - c_m\right)\right)\ \rho\,(p, c)\ dp = \\
&\overset{(2)}{=} Q\, \partial_{p_A} \left[\left(\alpha\, k\, p_A - c_m\right) \int_0^{+\infty} dc \int_0^{+\infty} \rho\,(p, c)\ dp \right] + \\
&+ Q\, \partial_{p_A} \int_0^{+\infty} dc \int_0^{+\infty} \max\,[p - c - k\, p_A; 0]\ \rho\,(p, c)\ dp = \\
&\overset{(3)}{=} Q\, \partial_{p_A} \left(\alpha\, k\, p_A - c_m\right) + Q\, \partial_{p_A} \int_0^{+\infty} dc \int_{c + k\, p_A}^{+\infty} \left(p - c - k\, p_A\right)\ \rho\,(p, c)\ dp = \\
&\overset{(4)}{=} Q\, \alpha\, k + Q \int_0^{+\infty} dc\, \partial_{p_A} \int_{c + k\, p_A}^{+\infty} \left(p - c - k\, p_A\right)\ \rho\,(p, c)\ dp = \\
&\overset{(5)}{=} Q\, \alpha\, k + \\
&+ Q \int_0^{+\infty} dc \left[\int_{c + k\, p_A}^{+\infty} -k\, \rho\,(p, c)\ dp - \left((c + k\, p_A) - c - k\, p_A\right)\ \rho\,(c + k\, p_A, c) \right] \\
&\overset{(6)}{=} Q\, \alpha\, k - Q\, k \int_0^{+\infty} dc \int_{c + k\, p_A}^{+\infty} \rho\,(p, c)\ dp \overset{(7)}{=} Q\, k\ \left[\alpha - \mathrm{Prob}\,(p > c + k\, p_A)\right]
\end{aligned}
$$

Note that if green certificates are considered, the formula just becomes

$$
\partial_{p_A} E\,[G] = Q\, k\ \left[\alpha - \mathrm{Prob}\,(p > c + k\, p_A + \alpha_{GC}\, p_{GC})\right]
$$

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