White Certificates for energy efficiency improvement with energy taxes: A theoretical economic model

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Abstract
In this paper we analyze interactions of a White Certificates scheme and existing energy taxation. We examine the effect of these policy instruments in the electricity sector, focusing on electricity producers and suppliers in a competitive market. With microeconomic theory we identify the total effect on the electricity price when suppliers internalize producers' reactions in their profit maximization decisions. The cases examined consist of electricity producers with carbon tax, electricity suppliers with sales tax and WhC obligations. Furthermore, we present a parallel implementation of WhC for electricity suppliers with carbon tax on producers, and a sales tax with WhC obligations to electricity suppliers. In addition, the paper analyzes the markets of energy efficiency projects and of White Certificates. The aim of this analysis is to discover the policy elements that affect the final price of electricity purchased by end-users. A basic finding is that in a merit order several parameters of these policies can increase final electricity price: demand for electricity and electricity supply cost at a large scale, followed by the level of sales tax, actual level of electricity sales, level of obligation for energy saving, and price of WhC (marginal costs of energy efficiency projects). The magnitude of impacts depends on values chosen and on initial positions of suppliers (if their actual behaviour deviates from full target compliance).

Introduction
In the past various national and international policies have been implemented in EU countries in order to improve energy efficiency (Oikonomou and Patel 2004). A traditional policy instrument for energy efficiency improvement is energy taxes and carbon taxes, which have been applied widely in many EU countries under different forms[1]. An important distinction of taxes and their effects based on Zhang and Baranzini (2004) is made between energy and carbon taxes. Energy taxes are excise taxes and target both fossil fuels and carbon free sources of energy production (or consumption) with an exemption of renewable energies. Energy taxes cover many economic sectors, mainly energy production (electricity generation), transport, industry, and electricity and natural gas end use. According to OECD/IEA statistics (2005), with regard to energy taxes on energy production and electricity use, the majority of EU countries possess a differentiated tax that consists of the energy tax itself and the VAT. They resemble more to sales taxes imposed on energy suppliers (or producers) and do not target CO_2 emissions reduction. A carbon tax is also an excise tax imposed on the carbon content of fossil fuels, therefore it addresses directly CO_2 emissions. An increase in the level of energy tax will be required in order to achieve the same emissions reduction in comparison to a carbon tax. A bottleneck in the EU internal energy market is that energy taxes are basically levied on elec-

1. More information on energy and carbon taxes in the EU can be found in the following studies: (Alfsen et al. 1995; Baranzini et al. 2000; Birkelund et al. 1994; Bosello and Carraro 2001; Christiernsson 2004; ECOTEC 2001; EEA 2004; Ghalwash forthcoming; Heijdra and van der Horst 2000; Manne and Richels 1993; OECD 2001; OECD/IEA 2000; Pearce 2006; Quirrion 2005; Schlegelmilch 2000; Vehmas 2005)

tricity consumption, rather than on the carbon-content of the fuels used for electricity production (OECD 2001). Countries that have introduced carbon taxes, although with many rebates, are Denmark, Finland, Ireland, Italy, the Netherlands, Norway and Sweden and more specifically concerning electricity production are still in place in Norway, UK and the Netherlands (Italy and Switzerland have abandoned them).

A relatively new policy instrument is White Certificates (WhC), named also as Energy Efficiency Titles. The basic idea underlying this policy instrument is that energy saving targets are set for energy suppliers (namely retailers) or distributors (in Italy), which must fulfil these requirements by implementing energy efficiency measures among their clients within a specific time frame. The fulfilment is acknowledged by means of (White) certificates. Energy suppliers or distributors, which overfulfill their targets, can sell their unused energy efficiency equivalents in the form of White Certificates to suppliers/distributors which have implemented fewer measures than according to their target. In the EU, only the UK and recently Italy and France have implemented WhC schemes, with different targets and design characteristics. In fact, electricity is mainly addressed but in order to avoid market distortions, policymakers can impose such obligations also on gas, fuel for domestic use and heat suppliers.

Literature has dealt in depth with economic analysis of various energy policy instruments (Baumol and Oates 1988; Boonekamp forthcoming; Bovenberg and Gurney 2005; Ekins and Barker 2001; Pezzey 2003; Pizer 1999; Pizer 2002; Weitzman 1975; Williams 2002). For the case of White Certificates most studies deal with analysis of the instrument and possible interactions, basically in the area of implications (Bertoldi and Rezessy 2006; Bertoldi et al. 2005; EU SAVE "White and Green" project; EuroWhiteCert project; Farinelli et al. 2005; Guardiola et al. 2004; Harrison et al. 2005; International Energy Agency. 2006; Langniss and Praetorius 2006; Mundaca and Santi 2004; Pagliano et al. 2003). Nevertheless, with the exception of Quirion (2005) an economic model of White Certificates with other policy instruments and implications to energy supplier's behaviour are not present.

The purpose of this paper is to create a framework that reveals possible interactions in the market structure and players' behaviour after the implementation of carbon taxes and White Certificates. This framework consists of profit maximization decisions of electricity producers and electricity suppliers when facing different policy instruments. Through the use of microeconomic theory we identify the total effect on the electricity price when suppliers internalize the behaviour of producers in their decisions. Our focus lies mainly on the parameters that influence final electricity price.

In section 2 we introduce the methodology used that consists of a microeconomic model alongside with some important assumptions. In section 3 we present the behaviour of electricity producers with and without carbon tax. Section 4 deals with two cases of electricity suppliers with and without an obligation of WhC, including a description of the WhC and energy efficiency markets. In section 5 a WhC scheme interacts with a carbon tax on electricity producers and finally in section 7 discuss our results and present some conclusions.

Methodology

We make use of a small microeconomic model depicting the business behaviour of energy suppliers in response to the actions of other stakeholders in the energy market, when both a WhC scheme and carbon tax (on input) is applied. We try to answer for each case what are the parameters that affect retail electricity market price and at what direction.

In our model we compare the WhC scheme for electricity suppliers with a carbon tax for electricity production, since tax for gas and other domestic fuels use is not yet present at least in most EU countries. Furthermore, we do not refer to electricity distributors, which have natural monopoly elements and can be subject to economic regulation. The reason is that we focus on competitive markets and we depict the business behaviour of energy suppliers that is determined by market provisions. Some basic assumptions of our model in the following sections are presented below:

Electricity suppliers under an energy efficiency obligation are assumed to function in a competitive market according to the principles of electricity market liberalization. Similar assumption holds also for electricity producers. We acknowledge that in many countries this is not the case so far, but following the electricity market liberalization targets set by the EU Commission (EC 2003), all EU countries must comply with. Given the reconsolidation tendencies in energy production and supply in the EU the market maintains an oligopoly character with limited production capacity and competitive prices. For the sake of simplicity and detail of analysis, we confine ourselves to competitive energy suppliers and producers[2]. Another assumption in our model is that electricity market is open and suppliers/ producers can export/ import electricity. Furthermore, there is no presence of electricity price regulation from authority.

End users' demand function for electricity in the model can also determine the level of energy efficiency due to price changes. Cost functions for producers and suppliers are not presented in detailed components and are aggregated to simple cost parameters. A detailed bottom up analysis can reveal numerous cost elements but our analysis focuses on how these market parties react in a general cost increase induced by policies.

Electricity producers

An average load electricity producer (generator) in a hypothetical competitive market faces the optimisation problem of maximizing his profit through selling electricity to energy suppliers at a market price, under fixed and variable costs. Fixed costs include the financing of plant construction and equipment leases, but their contribution to the market price is a small fragment due to their dispersion in the longer term. Variable costs consist of fuel expenses (namely fossil fuel) and operational costs. Operational costs refer to non-fuel, plant maintenance, and other capital costs. Total production cost that affects an electricity producer's profit over a given tie interval is obtained by multiplying the sum of electricity produced in each unit in megawatt

2. Otherwise the number of cases and the results would double and game theory should be employed, which would change the scope of this paper.

hours (MWh) with the operational cost (EURO/MWh)[3]. We assume also that there is a carbon tax on the fossil fuel input on production of electricity. With an imposition of a carbon tax on production, electricity producers optimize their behaviour by internalizing the tax rate in their decisions. The tax increases average and marginal costs of production, given that cost of other production factors remains stable. The producer's profit function can be presented as:

$$\Pi = PQ_P - \left[\frac{1}{2}(C_F + t_F)Q_P{}^2 + C_V Q_P \right]$$

where:

Q_p is MWh of electricity produced from fossil fuels

C_F is the uniform market price of fossil fuels (determined by the efficiency of the plant and quantity of fuels, given that no "two tiered oil pricing" for imported and domestic oil takes place)

t_F is the level of carbon tax and

C_V is the summation of all other variable costs.

We also assume a linear marginal cost function similar to Quirion (2005) and Ciarreta and Espinosa (2005), where plants have diminishing returns, due to limited availability of cheap sources[4].

In a competitive market, a producer's profit in the equilibrium market price is zero. We extract this result through the partial derivative of the profit function with respect to the quantity of electricity produced.

$$\frac{\partial \Pi}{\partial Q_P} = 0 \text{ , where } P = (C_F + t_F)Q_P + C_V \quad (1)$$

Equation 1 satisfies the first order condition of profit maximization under a competitive market, where price equals marginal profits and also equals marginal costs of electricity production. The second order condition is given by

$$\frac{\partial^2 \Pi}{\partial Q^2{}_P} = -(C_F + t_F) = \frac{\partial^2 C}{\partial Q^2{}_P} < 0$$

In this case, an individual energy producer sells electricity at a market price, which reduces his optimal profits at the level of the tax. An increase in the tax level will result in a loss of profitability (compared to the case where no carbon tax was imposed) but electricity producers will all react and increase the market price, since the tax is uniform and does not allow cost competitive positions. In an open market however, with a market price increase, domestic producers face a threat of cheaper imports of electricity (not taxed), reducing hence their domestic market shares. To sum up, a carbon tax can reduce profits from electricity generation especially to producers that cannot cover the increased variable policy induced costs. Sijm et al (2005) and Reinaud (2007) present also similar results in the sense that whether energy producers are in a competitive market or an oligopoly or monopoly, in principle the pass through rate of increased carbon costs (whether it is tax or emissions trading) from production to supply will be almost 100%.

Electricity suppliers

In this section we present a microeconomic analysis of the maximization problem of electricity suppliers with and without the implementation of energy savings through a WhC obligation.

Electricity suppliers purchase electricity from producers in a separate market, even though in reality many companies are still vertically integrated. They then sell purchased electricity to end-users (households, industry and tertiary sector). Both suppliers and producers are assumed not to possess any market power that could change the structure of the competitive market. Electricity suppliers differ from distributors and the transmission in terms of network management, since suppliers do not deal with the transport of electricity (given that electricity companies are not vertical) and can function in a competitive environment (while transmission and distribution are mostly natural monopolies). Sale of electricity includes metering, billing, marketing, and can be wholesale (large users) or retail (individual users) (Harris 2006; Steiner 2000). Relevant labour and capital costs during this procedure can be aggregated to energy supply cost (represented as EURO/MWh) used for electricity sold. We assume a linear marginal cost function for the same reasons stated for electricity producers in the previous section. The supplier's profit function can be presented as:

$$\Pi = P_S Q_S - \frac{1}{2} C_S Q_S{}^2 \quad (2)$$

where:

P_S is the final price of electricity,

Q_S is the quantity of electricity sold and

C_S is the energy supply cost.

The first component of the Equation are the revenues and the second the costs of suppliers. Note that the quantity of electricity that suppliers purchase from producers Q_P (see eq. 1) is internalised into their decisions. The final price P_S can differ from the original P due to a competitive market in the energy retail sector. Suppliers can sell electricity below the purchase price in order to maintain or increase their market shares initially and differentiate also their product (e.g. energy efficiency, renewable electricity).The ratio of electricity produced/sold is $Q_S=aQ_P$[5]. Moreover in excess demand conditions (i.e. when a>1), in order to cover domestic demand suppliers have to

3. Furthermore, as presented in Pepermans and Willems (2003) a clear distinction takes place between the base load plants and peak load plants, based on the highly variable demand and the non-storability of electricity. The former entail low marginal costs of production and high investment costs, while the latter the opposite. In our model we consider base load generation plants, since the analysis in the other case would require extra constraints in the quantity (namely production refrained to peak demand) and would blurry our policy objective.

4. This cost structure facilitates the solution of differential equations for electricity generation (Ciarreta and Espinosa 2005).

5. If a>1 then suppliers need to purchase energy from abroad in order to guarantee security of domestic supply. Parameter a can be also related to the efficiency of the whole electricity system, since grid loss takes place from production to transmission and distribution. This efficiency loss ratio in transmission and distribution can reach often up to 10% (EC 2006)

purchase electricity from abroad, or stimulate energy efficiency actions to their customers.

In a competitive market, a supplier's profit in the equilibrium market price is zero. We extract this result through the partial derivative of the profit function with respect to the quantity of electricity sold.

$$\frac{\partial \Pi}{\partial Q_S} = 0 \text{, where} \quad P_S = C_S \times a \frac{P - C_V}{C_F}$$

In this case, electricity suppliers charge a market price determined by their marginal cost of supply. It is clear that the latter also originates at a great extent from the marginal cost of electricity production. If demand rises (i.e. higher a) supply price rises and if prices of fossil fuels rise then supply price might increase, due to the reaction of all producers that increase the price. An individual supplier cannot affect directly the market price due to external factors that determine it (namely behaviour of competitive producers) and the large numbers of competitors.

If we assume a residential demand function for electricity we can extract the market equilibrium. We make use of a demand function from Fischer and Kayen (1962), where quantity of electricity demanded is a function of retail electricity price, income and stock of household appliances in use. Given that in the short and medium term demand responses to price of electricity are quite low (low elasticity of demand) the function can be written as:

$$Q_D = u(Y, P_S) * K$$

where:

Q_D is the quantity of electricity demanded (in equilibrium is the same with Q_S)

u is the utility rate of household appliances

Y is the household's income

K is the stock of appliances in use

An increase in income is expected to increase the overall increase in energy demand, while an increase in the electricity price (due to the price inelastic demand) will not decrease substantially electricity demand.

THE CASE OF WHITE CERTIFICATES

A White Certificates scheme for achieving higher energy efficiency is often imposed on electricity suppliers. Bertoldi *et al* (2005) and International Energy Agency (2006) present several variations in terms of design and targets set in Italy, France and the UK. As far as design is concerned, WhC can function in a simple form (i.e. suppliers fulfil their obligations, receive WhC and can trade them in a certificate market), or more complex, involving also financial mechanisms, such as taxes and subsidies, for stimulation of energy efficiency actions and involving more actors, like Energy Service Companies (ESCO) that can be issued white certificates coming from their day-to-day activity and sell them in a certificate market to the obliged actors, such as energy distributors or suppliers. The scheme is based on an obligation imposed on energy suppliers that must implement energy efficiency projects to their customers and by doing so they fulfil their target and receive WhC.

Target allocation can be uniform (same for all suppliers) or differentiated (individual for each supplier). In both cases moreover a target can be absolute (i.e. fixed amount of energy savings) or relative to electricity sales (i.e. proportioned to the sales of the supplier, considering the weight of the supplier in ratio with the national amount of energy sold yearly by all the national suppliers). The price of WhC in theory reflects the marginal costs of implementing energy efficiency projects (shadow price) or the relevant value of energy saved.

In our model we assume a uniform target relative to electricity sales, where energy efficiency actions must take place among domestic end users. A supplier can sell electricity but a proportion of these sales must correspond to implementation of energy saving projects (obligation), where he receives WhC, after projects are accredited. We consider that suppliers prefer implementing energy efficiency projects mainly to their own electricity customers, since already established relationships exist and information, communication and negotiation costs can thus be lower. Furthermore, a supplier's implementation of specific energy efficiency projects can create a market lock-in for other suppliers that will shift their investments towards similar competitive products. The actual percentage of electricity that a supplier sells on the market can differ from his obligation, depending on market strategies and profitability margins. A supplier faces hence two options: a) purchasing WhC in order to fulfil his target or b) implementing energy efficiency projects to end users. If the target is overfulfilled, the supplier can finance part or all the cost of his energy efficiency projects by selling WhC to suppliers that cannot meet their targets. If a supplier cannot fulfil his target or purchase WhC, a sanction in the form of financial penalty is imposed. In theory, that penalty should be higher than WhC market price, in order to induce supplier's behaviour towards implementing energy saving projects or purchasing WhC[6].

The supplier's revenues and costs from electricity sales (modified from eq.2) are:

$$P_S(1-\beta)Q_S - \frac{1}{2}C_S(1-\beta)Q_S^2$$

where the new parameters are:

β is the baseline percentage of electricity sales upon which the mandatory energy efficiency target is set,

(1-β) is the percentage of energy saving that is required for the fulfilment of the target (represents the actual target),

The supplier's revenues and costs from the WhC obligation are:

$$P_{WhC}\delta_1(1-\beta-\gamma)Q_S - P_{PEN}\delta_2(\gamma-(1-\beta))Q_S$$

where:

P_{WhC} is the price of WhC as a shadow cost of energy efficiency projects,

6. Nevertheless, the penalty can take various forms, as a fixed ceiling price or as a percentage of a supplier's turnover (Energy Efficiency Commitment in the UK).

P_{PEN} is the level of penalty and
γ is the actual sales behaviour of the supplier, which is endogenous in the model and depends on P_{WhC} and P_S
δ_1 is the supplier's opportunity cost on buying/selling WhC
δ_2 is the supplier's opportunity cost on paying the penalty.

The supplier's new profit function can be presented as:

$$\max \Pi = P_S(1-\beta)Q_S + P_{WhC}\delta_1(1-\beta-\gamma)Q_S -$$

$$\frac{1}{2}C_S(1-\beta)Q_S^2 - P_{PEN}\delta_2(\gamma-(1-\beta))Q_S \quad (3)$$

The first two elements in this Equation are the revenues from electricity and from WhC sales and the last two are costs of the supplier (supply costs and penalties). As can be understood, if a supplier cannot fulfil his target, the second element is negative and transforms to cost, through purchasing WhC. We distinguish three cases of compliance:

- if $1-\beta < \gamma$ the target is lower than the actual level of electricity sales, then the target is overfulfilled, i.e. generated energy savings provide a surplus of WhC that can be sold
- if $1-\beta > \gamma$ the target is higher than the actual level of electricity sales, meaning that a supplier needs to implement more energy efficiency projects, purchase WhC or pay the penalty
- if $1-\beta = \gamma$ then the target is achieved, so all WhC acquired from energy efficiency actions are redeemed and no surplus or shortage is present

A basic conceptual difference between β and γ is that the former is imposed by government while the latter demonstrates the supplier's strategy. In one more detailed step, we express furthermore the tradeoff of a supplier on buying WhC (alternatively implementing energy efficiency projects) or paying the penalty with the symbols δ_1 and δ_2 ($\delta_1=1-\delta_2$, with values 0 to 1). If $\delta_1=1$ the supplier prefers to cover his obligation with WhC and avoid paying penalty, while if $\delta_2=1$ he does not participate in the process of implementing energy saving projects and prefers to pay the penalty[7].

In a competitive market, market equilibrium is where profit derivative equals to zero, which leads to the Equation of supplier's marginal costs with a competitive market price. We extract this result through the partial derivative of the profit function with respect to the quantity of electricity sold.

$$\frac{\partial \Pi}{\partial Q_S} = 0 \text{, where } P_S = C_S \times a\frac{P-C_V}{C_F} +$$

$$\frac{\delta_2(\gamma-(1-\beta))P_{PEN} - \delta_1(1-\beta-\gamma)P_{WhC}}{1-\beta}$$

We can deduce from this relationship that if demand rises (i.e. higher a) or other costs rise, supply price rises due to the reaction of all producers that increase their price. A supplier cannot affect directly the market price due to the external factors that determine it (namely behaviour of competitive producers). With a WhC scheme, price of supplied electricity is also determined by the relative difference of penalty with certificate price, level of target (β), and tradeoffs of purchasing WhC (δ_1) or paying the penalty (δ_2).

When a supplier meets his energy efficiency target up to the level of the obligation, it is clear that no extra costs are incurred. If all suppliers manage to achieve this result, then price of electricity is in equilibrium and no pressing effect is present. In this situation, no trade of WhC takes place since the targets are achieved (i.e. there is no demand or supply for WhC), and the added value of the scheme towards an obligation without trading is not present anymore. If an energy efficiency obligation is lower than a supplier's actual electricity sales, then he can decide to sell more electricity up to the maximum allowed level, or sell electricity more than his target because his opportunity cost of paying the penalty (for not complying with the obligation) is lower than selling more electricity, or to achieve more energy savings than his target, which grants him with a surplus of WhC that can be sold in the market. If an obligation is higher than actual electricity sales, then a supplier faces the option of reducing his electricity sales while performing energy efficiency projects to achieve the target, maintain his relatively high electricity sales and purchasing WhC, or paying the penalty.

At an initial phase, when no-regret energy efficiency potentials exist, energy efficiency projects are expected to carry a low cost. This cost in a competitive energy efficiency products market will determine also the price of WhC (as a marginal shadow price of the next least expensive energy saving project). A low P_{WhC} influences moderately the optimal price. When P_{WhC} increases it presses optimal P_S upwards, which in fact can increase the incentive for energy efficiency actions, since financing of such projects can be fulfilled through an increased market electricity price (given that suppliers will react and formulate a new market equilibrium). An increase in penalty price will also press P_S upwards, while it will have no effect if a supplier fulfils his obligation solely through WhC trading. Furthermore, an increase of the target can lead to an increasing effect to the equilibrium price of electricity, assuming that suppliers cannot comply with the new target. A failure of compliance, (reflected in high values of γ) affects P_S positively, while an overcompliance lowers the P_S. A fulfilment of the target (either with energy efficiency measures or purchase of certificates) in equilibrium can affect P_S in both directions, depending on the initial point of a supplier. We could expect that most probably, suppliers should increase P_S in order to carry over increased policy costs.

7. Another strategy for the supplier, in theory, could be the partial fulfilment of the target through purchase of WhC and the remaining part through paying the penalty. In reality nevertheless that WhC trading periods are relatively short (yearly basis), a supplier chooses the lowest compliance price and decides to cover his obligation with the same cost. Still, a tradeoff between these two options can take place and a supplier can choose a portfolio of options (e.g. 1 and 2 simultaneously at a certain rate).

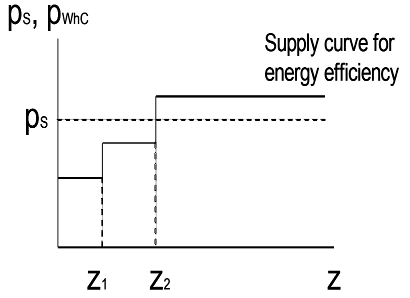

Figure 1: Supply of energy efficiency projects

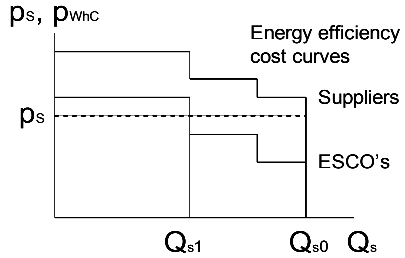

Figure 2: Cost of supply of energy efficiency projects

Nevertheless, in all the above mentioned effects, an individual supplier's competitive position does not allow him to raise the price and therefore he can optimise his revenues or cost parameters or combinations of them. More specifically, supplier's extra costs should be financed through his increase in sales (Q_S), his implementation of least cost energy efficiency projects, his lowering of inputs cost (Q_P), by choosing the least cost producer who sells below market price), his lowering supply costs (C_S), or by selecting a network with the least grid loss (minimize a). Another strategy a supplier can follow is the contracting of Energy Service Companies (ESCO's) or other market parties in order to implement energy saving projects in a more profiTable way and increase his share in the energy service market. Such projects consist of technologies with a high market potential and cost effectiveness[8].

Based on the residential demand function we expect that an energy efficiency obligation will change the quality of the stock of appliances in use (K), while an increase in P_S will not have a strong effect on their utility rate (u). The net total effect in this case will be a reduction in the quantity of electricity demanded. Nevertheless we must take into account the rebound effect (originating from an income effect), where the relative increase of income (due to lower electricity bill) can possibly stimulate a higher utility rate and the positive effect can be reduced. Finally, if we consider information campaigns as an extra measure implemented by electricity suppliers, this can stimulate a more energy efficient behaviour of the end users, which leads to a lower u and hence a lower electricity demand.

MARKET OF ENERGY EFFICIENCY PROJECTS

We demonstrate in this section how a market of energy efficiency projects can function, based on the decisions of an energy supplier for the fulfilment of his energy efficiency obligation under a WhC scheme.

Energy efficiency projects are supplied as showed in Fig 1. The step supply function represents unit costs for such projects: using unit costs instead of marginal is not orthodox but gives a more realistic view of the market. The units of energy savings from such projects are symbolized as z and in fact is the actual behavior of energy suppliers $(\gamma-(1-\beta))Q_S$, as expressed above.

Cost effective energy efficiency projects are provided in the market given that their marginal costs do not exceed the price of electricity (p_s). For points z_1 and z_2 in Fig. 1, all areas between the p_s and the supply curve of energy efficiency projects represent the total savings in the electricity bill of end-users.

Departing from Figure 1 we obtain the symmetrical Figure 2 with the costs of energy efficiency projects running from right to left. The x axis in this case reflects quantity of electricity sold (Q_s) and two cost curves are present: the highest for energy efficiency projects managed by suppliers, the lowest for ESCO's.

Starting with the business as usual energy consumption (Q_{s0}), a project by an ESCO could reduce it to (Q_{s1}), given the price of energy (p_s), with a private benefit amounting to the difference between price line and cost curve. If the project is managed by an electricity supplier the energy efficiency project's cost curve shifts upward: in fact, a part contains the direct cost of the project, if the project is implemented in the area served by the supplier we should also consider the reduced income due to lower bills. The average supplier facing mandatory targets of energy efficiency with a white certificate scheme would reasonably try to minimize the overall cost of the policy.

Linking up to the electricity supplier's behavior as described above, by inserting in the profit maximization problem the costs of energy efficiency projects $C_{EE,}$ we modify Equation 3. These costs do not reflect the shadow prices of WhC, hence assuming that a price of WhC is dependent on the market demand and supply of energy efficiency projects as expressed in Figures 1 and 2. In this sense C_{EE} is not derived from the model but is imposed exogenously and modifies suppliers' behaviours. The new market equilibrium is:

$$P_S = C_S \times a\frac{P - C_V}{C_F} + \frac{\delta_2(\gamma - (1-\beta))P_{PEN} - (1-\beta-\gamma)(C_{EE} - \delta_1 P_{WhC})}{1-\beta}$$

We can deduce that the costs of energy efficiency projects press price of electricity upwards and must be counterbalanced by a relative increase in the price of WhC, where suppliers can compensate their incurred costs.

A MARKET ANALYSIS OF WHITE CERTIFICATES

In this section we analyze the behaviour of demand and supply forces in the market of WhC. The basic component of the supply curve of WhC is the availability of cost effective energy efficiency projects. Their implementation generates WhC attributed to electricity suppliers and ESCO's. The behaviour of these market players is differentiated in terms of trading WhC.

8. In reality, a typical measure that dominates market potential in such schemes (especially in the UK) is insulation, see for instance OFGEM (2003).

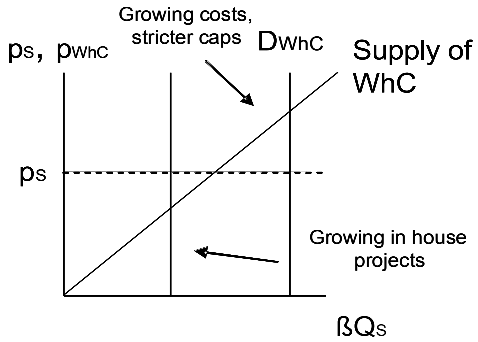

Figure 3: Supply and demand forces in the market of WhC

As far as electricity suppliers are concerned, the amount of certificates corresponding to mandatory targets is surrendered at the end of every policy period to demonstrate compliance. If suppliers have exceeded their target, the possible surplus can be stored for future periods or supplied in the market of WhC through official exchange or private contracts.

ESCO's and other market parties, on the contrary, sell all the basket of WhC obtained from eligible projects to electricity suppliers or other parties interested in arbitrage, since they cannot carry over their savings for next periods. The option hence of selecting δ_1 and δ_2, as well as the P_{PEN} for ESCO's are non-existent, therefore their maximization problem is substantially different.

Based on our analysis so far, the supply curve of WhC will react positively to policy targets, p_s, subsidies and technology improvement, negatively to transaction costs. Differences in short and long-term reaction are not considered.

The overall demand curve for WhC (D_{WhC}) take form according to two main components: mandatory and free demand. The mandatory demand stems out from suppliers for the part of energy efficiency cap not realized in households (vertical demand). The free demand stems out from third parties and depends on expectations about prices and technologies. Figure 3 presents this situation in the market of WhC.

Microeconomic analysis with policy interaction

In this section we analyse the normative behaviour of electricity suppliers under a WhC scheme that incorporate the costs of electricity production, when a carbon tax on producers is applied.. Finally, we present the degree of significance of each parameter on the final decisions of the market, as reflected by their impact on the final price of electricity.

ELECTRICITY SUPPLIERS WITH WHC OBLIGATION WITH ENERGY PRODUCERS WITH CARBON TAX

In a competitive market with a carbon tax electricity producers optimize their behavior by internalizing the tax rate in their decisions (eq.2). An electricity supplier under an energy efficiency obligation in a WhC scheme can sell electricity and must fulfil an energy efficiency obligation as a proportion to his electricity sold through implementing energy efficiency projects, purchasing WhC, or paying the penalty. In the case where both instruments are being implemented simultaneously, a supplier's profit function, when taking into account the effect on producer is:

$$\max \Pi = P_S(1-\beta)aQ_P + P_{WhC}\delta_1(1-\beta-\gamma)aQ_P -$$

$$\frac{1}{2}C_S(1-\beta)aQ_P - P_{PEN}\delta_2(\gamma-(1-\beta))aQ_P$$

A supplier internalizes the producer's tax burden in his decision and sells electricity at the competitive price. We extract this result through the partial derivative of the profit function with respect to the quantity of electricity sold.

$$\frac{\partial \Pi}{\partial Q_S} = 0 \text{, where} \quad P_S = C_S \times a\frac{P - C_V}{C_F + t_F} +$$

$$\frac{P_{PEN}\delta_2(\gamma-(1-\beta)) - \delta_1(1-\beta-\gamma)P_{WhC}}{1-\beta} \qquad (4)$$

Similar to the previous cases, we can demonstrate that if demand rises (i.e. higher a) supply price rises but with higher prices of fossil fuels due to the carbon tax, supply price in this case will definitely increase, due to the reaction of all producers that increase the price. A supplier cannot affect directly the market price due to external factors that determine it (namely behaviour of competitive producers). An increase in producer's fossil fuel cost will tend to increase the price of final electricity sold in the retail market or increase imports from cheaper sources.

When P_{WhC} increases it presses the optimal market P_S even more upwards, which jeopardizes the incentive for energy efficiency actions, since suppliers might prefer not to lose their market shares in electricity competition and hence sell from cheaper sources at lower prices. A counterargument is that if supplier's market positions are guaranteed then they could indeed reduce their electricity sales and promote energy efficiency. In all senses this behaviour depends on the level of the price increase due to the carbon tax and on the supplier's initial position. Furthermore, a determinant parameter is the difference of carbon tax with price of WhC in the market. If prices of WhC are higher than the tax, then the tax acts as a lower bound price for energy efficiency, which is not necessarily favourable, since energy efficient solutions that are initially economically efficient might be locked out. In this case, a carbon tax could distort the market for energy efficiency stimulated by WhC. If prices of WhC are lower than the tax, then the increase in the costs will stimulate a lot of cost effective energy efficiency actions in a merit order, which could exhaust the low hanging fruits, but most probably the allocation of costs would not be efficient. Finally, another determinant parameter is the difference of the penalty with the level of carbon tax. When the tax is much lower than the penalty, the relative impact on the price of electricity will not be substantial and energy efficiency projects can be locked up due to their lack of competitiveness. If the tax is higher then eventually energy efficiency actions will be stimulated and become profitable, as long as their costs for the suppliers still remain under the level of the penalty. If finally, the carbon tax is higher than the penalty, then the price of elec-

Table 1: Parameters affecting price of electricity, price and volume of WhC

	P_{WhC}	P_S	B	α	C_S	t_F
P_{WhC}	X	+	-	+	-	+
P_S	+	X	+	+	+	+
WhC	-	-	+	-	+	-

tricity can rise a lot and suppliers might just pay the penalty and maintain their profits (through higher revenues).

An increase in penalty price will press also P_S upwards, while it will have no effect if the supplier fulfils his obligation solely through WhC trading. A failure of compliance, (reflected in high values of γ) affects P_S positively, while an overcompliance lowers P_S. Through the imposition of a carbon tax on the producer, electricity supplier's input is more expensive, therefore a percentage of this cost will be passed on to energy efficiency projects or directly to electricity price, based on cost pricing. Since supplier's competitive position does not allow him to raise the price and since his input is already more expensive, his extra costs should be financed through increasing sales (Q_S), implementing least cost energy efficiency projects (e.g. contracting ESCO's), lowering of inputs cost (aQ_P), choosing the least cost producer who sells below market price, lowering supply costs (C_S), or by selecting a network with the least grid loss (minimize a).

As far as electricity demand is concerned, we expect that an increase that no substantial added value will take place from the introduction of a carbon tax upon the electricity consumption, given that a WhC obligation also takes place. This is due to the fact that price elasticity of demand for electricity is rather low and hence the effect on a price increase cannot stimulate only by itself an extra energy efficient behaviour. This gap can be covered by energy efficiency measures implemented through a WhC scheme.

INFLUENCING FACTORS ON THE PRICE OF ELECTRICITY

As depicted in this section, different sorts of taxation when combined with WhC lead electricity suppliers to different optimizing behaviours. Electricity suppliers in a competitive environment receive market signals and incorporate prices, taxes and their energy efficiency obligations to their decisions. Parameters that influence the final market price are: price of WhC, level of obligation, actual percentage of electricity sold, level of sales tax, level of penalty, electricity demand, and cost of supply.

In Table 1 we present the influence of the above mentioned parameters on the price of the WhC, on the price of electricity, and on the volume of WhC that is an inverse factor of realization of energy efficiency projects (less demand for certificates because obligations are achieved through projects). In terms of policy interaction, we identify that a tax on fossil fuels on producers provides a better incentive for energy efficiency than a tax on sales to suppliers that cover policy costs with an increase of electricity market price. An increase of the level of the obligation under WhC or of the cost of electricity supply will reduce P_{WhC} and suppliers will prefer to purchase certificates than implementing projects. The magnitude of impacts of parameters depends on the values chosen and on the initial position of suppliers (i.e. if their actual behavior deviates from full compliance with targets)[9].

Discussion and conclusions

In this paper we have analyzed interactions of two energy policy instruments, namely a WhC scheme as an innovative policy instrument for energy efficiency improvement and existing energy taxation. Due to the multiplicity of energy taxes, we confine ourselves to a tax on fossil fuels as an input for electricity production (carbon tax). WhC and carbon taxes differ in terms of objectives and final impacts on the price of electricity. WhC are implemented recently in the UK, France and Italy, under various forms, and carbon taxes in few EU countries, with different rates and rebates.

We examine the effect of these policy instruments in the electricity sector, focusing on electricity producers and suppliers in a competitive market. All other market parties (e.g. electricity end-users) are considered exogenous to our analysis. Through the use of microeconomic theory we demonstrate the total effect on the electricity price when suppliers internalize the behaviour of producers in their profit maximization decisions. Our focus lies mainly on the parameters that influence final electricity price that electricity suppliers charge on the market.

We present some basic assumptions in our economic model, mainly in the context of competition and electricity demand. We acknowledge however that our model refers to an ideal market situation of full liberalization, which in most countries is not the case so far. Oligopolistic or monopolistic tendencies through vertical integrations of energy companies still dominate the field. We make use of these simplifications in order to convey market behaviour of electricity suppliers when facing different policies.

The cases we have examined consist of electricity producers with and without a carbon tax, and electricity suppliers with and without WhC obligations. Furthermore, we present a parallel implementation of WhC for electricity suppliers with carbon tax on electricity producers. In this case, we present the differences in optimization behaviour of producers and suppliers and how the optimal decisions (alias profit maximization decisions) of electricity producers are incorporated in the optimization decisions of electricity suppliers. Given also that WhC refer to undertaking of energy efficiency actions, we present possible tradeoffs in business strategies between reducing electricity supply costs and implementing energy saving projects.

A basic finding is that in a merit order several parameters can increase final electricity price when different policies are implemented: demand for electricity and electricity supply cost

9. We have identified some threshold values in the model, which can act as restrictions, for instance very low prices of electricity result in negative WhC prices.

at a large scale and then follow the actual level of electricity sales, level of obligation for energy saving, and price of WhC (representing the marginal costs of energy saving projects). Some parameters that influence positively the price of WhC are: price of electricity, level of demand, and the level of carbon tax, while negative impact is found on the level of obligations and electricity supply cost. Finally, energy savings (represented indirectly by quantities of WhC traded) are affected positively by the level of obligation and cost of electricity supply, while negatively by the price of WhC, price of electricity, level of electricity demand, and the level of carbon tax. The magnitude of impacts of parameters depends on the values chosen and on the initial position of suppliers (i.e. if their actual behaviour deviates from full compliance with targets).

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