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Efficiency and Distributional Impacts of Tradable White Certificates Compared to Taxes, Subsidies and Regulations

Summary

Tradable White Certificates (TWC) schemes, also labelled Energy-Efficiency Certificates schemes, were recently implemented in Great Britain, Italy and France. Energy suppliers have to fund a given quantity of energy efficiency measures, or to buy so-called "white certificates" from other suppliers who exceed their target. We develop a partial equilibrium model to compare TWC schemes to other policy instruments for energy efficiency, i.e., energy taxes, subsidies on energy-saving goods and regulations fixing a minimum level of energy-efficiency. The model features an endogenous level of energy service and we analyse the influence of the substitutability between energy and energy-saving goods to produce the energy service, as well as the influence of the elasticity of demand for the energy service. We show that if the level of energy service consumption is fixed, a TWC scheme is as efficient as an energy tax, but that it is much less otherwise because it does not provide the optimal incentive to reduce the consumption of energy service. This inefficiency is worsened if energy suppliers' targets are fixed rather than proportional to the suppliers' current output. On the other hand, compared to taxes, a TWC scheme allows reaching a given level of energy savings with a lower increase in the consumers' energy price, which may ease its implementation.

Keywords: Energy Saving Policies, Energy-Efficiency Certificates, White Certificates, Rebound Effect

JEL Classification: Q38, Q48, Q58

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Introduction

Energy efficiency and energy savings, which had somewhat dropped from the political agenda following the counter-oil shock of the late 1980's, have recently raised more attention, especially due to climate change and security of supply concerns. Meanwhile, the end of state monopolies in the electricity and gas sectors has led to design new policy instruments to save energy.

In particular, energy efficiency certificates, dubbed Tradable White Certificates (TWC), were recently implemented in Great Britain (UK Ofgem, 2005; Sykes, 2005), Italy (Pagliano et al., 2003; Pavan, 2005) and France (Moisan, 2004; Dupuis, 2007). Setting aside various differences among these systems, they may be schematically described as follows. Energy suppliers have to generate a given quantity of energy savings, or, if they are short of their target, to buy certificates from other suppliers. Vice versa, suppliers who have funded more measures than their target are allowed to sell such white certificates to those who are short of their target. In general, in order to be taken into account, energy savings have to take place in energy consumers' dwellings or plants, not in energy suppliers' facilities. In practice, suppliers typically fund energy savings in their own customers' dwellings, or contract with retailers who increase their sales of energy-efficient goods in exchange for a funding from the energy supplier.

The peer-reviewed literature on TWC schemes is increasing but still scarce. Langniss and Praetorius (2006) as well as Mundaca (2007) discuss the transaction costs associated with the generation of TWC and their implication for TWC markets, an issue that we do not address here. Bertoldi and Huld (2006) discuss some implementation issues as well as the interaction of TWC schemes with other trading systems, a question that we do not address either. Vine and Hamrin (2008) present the experience to date with TWC schemes and outline potential opportunities in the United States. Farinelli et al. (2005), Mundaca (2008) and Oikonomou et al. (2007) quantify the potential for a TWC scheme, in Europe for the first two papers and in the Netherlands for the latter. To date, an analysis of the economic mechanisms at stake when implementing a TWC scheme and of its relative efficiency compared to other policy instruments seems to be lacking.

In the present paper, we compare two types of TWC schemes to other policy instruments for energy efficiency, i.e., taxes, subsidies and regulations. On this purpose, we develop a simple partial equilibrium model representing the markets for four commodities: energy, energy-saving goods or services, a composite good and TWCs. This paper builds on a working paper by Quirion (2006) but enhances it by (i) using more general functional forms (CES instead of Cobb-

Douglas) thereby allowing a sensitivity analysis of the elasticities; (ii) allowing for an endogenous level of energy service; (iii) assessing another policy instrument (the subsidy).

Although this simple model cannot by far address all the issues raised when choosing between TWC schemes and other policy instruments, it is able to shed a first light on their economic efficiency and on their contrasted distributional consequences.

The paper is organised as follows. In the first section we present some background information on TWC schemes in practice. The first model and the policy instruments are presented in section 2 and numerical results in section 3. These results are discussed in section 4 and section 5 concludes. Appendix 1 lists the model's variables and parameters and Appendix 2 provides the method used to compare the national targets.

1. Tradable white certificates in practice

What is generally called a TWC is the commodity potentially traded between suppliers[1]. A TWC scheme can then formally be understood as an obligation to save a given quantity of energy coupled with a flexibility mechanism, actually the market for TWCs. Although this instrument targets potentially every final consumption sector (including industry or transports), it focuses in practice on existing buildings (mainly residential but commercial as well), considered as the greatest potential for cost-efficient energy savings.

Although the existing schemes in the UK, Italy and France largely conform to this definition, there are some differences among them, for example the obligation to achieve half of the target in poor households in the UK.

In the UK, the first such system, labelled the "Energy Efficiency Commitment" (EEC1), required suppliers to save 62 TWh of energy in three years, from 1st April 2002 to 31 March 2005. This target refers to savings cumulated and discounted over the lifetime of the equipments funded, not only over the 3-year commitment period. This aggregate goal was exceeded by 40% and the suppliers who exceeded their target were allowed to bank these energy efficiency measures for the second period (EEC2), running from 1st April 2005 to 31 March 2008, with a roughly twice more ambitious target of 130 TWh. This was indeed the reason for the overachievement of the target: as in the U.S. SO_2 cap-and-trade programme (Ellerman and Montero, 2002), emitters used the banking provision to ease the transition between the first and the second (more ambitious)

[1] Bertoldi and Rezessy (2006, p. 35) give the following definition: “A white certificate is an instrument issued by an authority or an authorised body providing a guarantee that a certain amount of energy savings has been achieved. Each certificate is a unique and traceable commodity that carries a property right over a certain amount of additional savings and guarantees that the benefit of these savings has not been accounted for elsewhere”.

commitment period. Twelve suppliers groups were set a target under the EEC. Among them, two did not meet their target, generating a shortfall of nearly 1 TWh. Since these companies had ceased energy trading, no penalty was imposed on them because it would have served no practical purpose.

To tackle "fuel poverty", at least half of the target had to be achieved in the "Priority group", defined as those households receiving certain-income related benefits and tax credits. This requirement was fulfilled during EEC1. The last available information indicates that one quarter before the end of the EEC2, the target had already been overachieved by 26%, including the carry-over from EEC1 (UK Ofgem, 2008). Although committed suppliers were allowed to trade commitments or energy efficiency activities, such trades occurred neither in the first nor in the second period.

Note that for the third period (2008-2011) the government replaced the EEC by the CERT (carbon emission reduction target) with the following characteristics: a target expressed in CO_2 equivalent rather than in energy; a roughly doubled quantitative objective (154 Mt CO_2); a larger scope including micro-generation and biomass heating; and increased trading opportunities (UK Ofgem, 2008).

In France, the three-year scheme started in July 2006 and the target is 54 TWh, also cumulated and discounted over the lifetime of the equipments funded. The latest available data show that 14 TWh have already been achieved, most of them (95%) in the residential sector. The actor's strategies are still not well described, but we know that some agents have already banked some certificates.

In Italy, the five-year scheme started in 2005, but energy saved by suppliers between 2001 and 2004 can be accounted to achieve the target until 2009. The 2005 and 2006 targets were respectively 0.2 and 0.4 Mtoe (million tonnes of oil-equivalent) increasing each year up to 2.9 Mtoe in 2009. Contrarily to the two other TWC schemes, these figures refer to annual savings, neither cumulated nor discounted. The 2005 and 2006 targets were both largely exceeded and 240% of the 2006 objective were achieved, including the 2001-2004 savings. In comparison to the British scheme, the Italian one has an active market since 24% of the certificates or “titles” (equivalent to one toe) delivered have been traded (76% through bilateral transactions and 24% on a specific market). Between 2006 and 2007 the part of traded titles has increased from 17 to 24% and the average market price has decreased (-57% for electricity titles and -11% for gas titles).

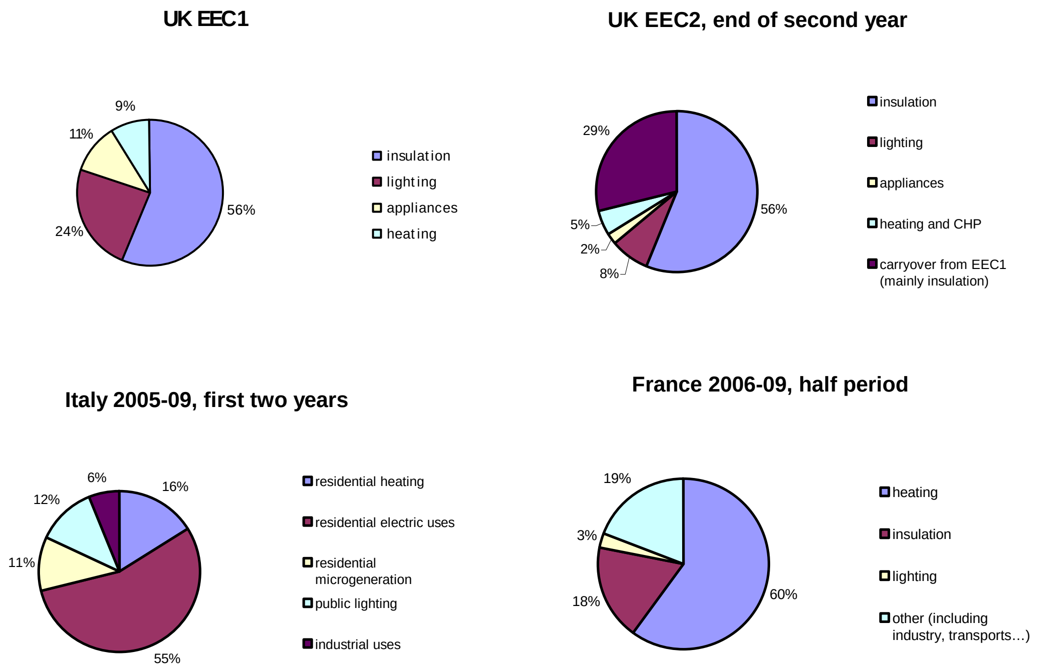
In Table 1 we compare the targets in the three existing TWC schemes by translating them in a standardised unit, which leads to the following results (see Appendix 2 for calculation steps and hypotheses). As is apparent from table 1, these targets amount to roughly 1 to 2% of final national energy consumption.

Table 1. Targets in the British, Italian and French schemes

	UK 02-05	UK 05-08	Italy 05-09	France 06-09
Absolute target (cumulated & discounted)	27 TWh/year	43 TWh/year	21 TWh/year	18 TWh/year
Target in % of final energy consumption	1.4	2.3	1.5	0.9

The savings occur through different measures as indicated in Figure 1, based on reports from the public bodies in charge of the TWC schemes (UK Ofgem 2007, AEEG 2007 and DGEMP 2008). It appears that even though similar measures are addressed in different countries their share in the savings differs a lot. For further developments on the existing TWC schemes see the above-mentioned references, Bertoldi and Rezessy (2006) or Giraudet (2007).

Figure 1. Types of saving in the existing TWC schemes



2. The model[2]

2.1. The model in business-as-usual (i.e., no energy-saving policy)

This simple partial equilibrium model features four agents (box 1): energy consumers (who may be firms or households) buy energy (labelled *e*) and energy-saving goods or services (labelled *g* for "green") to generate a certain level of energy service *ES* (figure 2)[3]. ES is "produced" by consumers, by combining *e* and *g* in a CES function, with an elasticity of substitution σ_b.

Consumers choose the combination of *e* and *g* that minimises their cost subject to the constraint that energy service reaches a level *ES*.

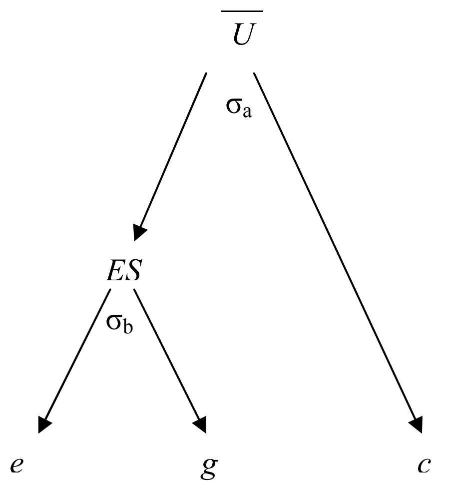
Consumers also buy a composite good labelled *c*, which is combined with *ES* in a CES function, with an elasticity of substitution σ_a, to create utility. Consumers choose the combination of *ES* and *c* that minimises their cost subject to the constraint that utility reaches an exogenous level

[2] The model is coded using Scilab and the code is available from the authors upon request. Appendix 1 lists the variables and parameters.

[3] Examples of energy services are transportation, light or heat. *ES* thus represents a certain number of kilometres travelled at a certain speed, comfort and reliability, a number of lumens/m², the heating of a dwelling at a certain temperature, etc. Examples of goods and services represented by *g* are thermal insulation panels, energy-saving devices that make a fridge-freezer more energy-efficient, and so on.

$\bar{U}$. Throughout the paper we take $\sigma_a < \sigma_b$ to represent the fact that *e* and *g* are closer substitutes to one another than to *c*.

Figure 2. Consumer demand system



Firms maximise their profit under perfect competition and produce under linearly decreasing returns. Our model represents the short term, i.e. the productive capital is fixed, hence the assumption of decreasing returns. We assume that public authorities do not intervene in price setting, and especially that the energy market is fully liberalised. Without loss of generality, we normalise the number of firms and consumers to one in order to simplify the notations, but we assume that the real number is large enough for them to be price-takers on all markets.

Box 1. Model equations in business-as-usual

Formally we have two optimisation programs, both minimising consumer cost under a quantity constraint:

$$(A)\begin{cases} \underset{\{ES,c\}}{Min}\, P_{ES}\cdot ES + P_c \cdot c \\ s.t.\,\overline{U} = (\alpha_{ES}\cdot ES^{\frac{\sigma_a-1}{\sigma_a}} + \alpha_c \cdot c^{\frac{\sigma_a-1}{\sigma_a}})^{\frac{\sigma_a}{\sigma_a-1}} \end{cases} \tag{1,2}$$

$$(B)\begin{cases} \underset{\{e,g\}}{Min}\, P_e\cdot e + P_g \cdot g \\ s.t.\,ES = (\alpha_e\cdot e^{\frac{\sigma_b-1}{\sigma_b}} + \alpha_g \cdot g^{\frac{\sigma_b-1}{\sigma_b}})^{\frac{\sigma_b}{\sigma_b-1}} \end{cases} \tag{3,4}$$

First-order conditions lead to good demands:

$$ES_d = \alpha_{ES}{}^{\sigma_a} \left(\frac{P_U}{P_{ES}} \right)^{\sigma_a} \overline{U} \tag{5}$$

$$c_d = \alpha_c{}^{\sigma_a} \left(\frac{P_U}{P_c} \right)^{\sigma_a} \overline{U} \tag{6}$$

$$e_d = \alpha_e{}^{\sigma_b} \left(\frac{P_{ES}}{P_e} \right)^{\sigma_b} ES \tag{7}$$

$$g_d = \alpha_g{}^{\sigma_b} \left(\frac{P_{ES}}{P_g} \right)^{\sigma_b} ES \tag{8}$$

where P_u (resp. P_{ES}) is the shadow price of program A (resp. B), respectively defined by the following equations:

$$P_U{}^{1-\sigma a} = \alpha_{ES}{}^{\sigma a} P_{ES}{}^{1-\sigma a} + \alpha_c{}^{\sigma a} P_c^{1-\sigma a} \tag{9}$$

$$P_{ES}{}^{1-\sigma b} = \alpha_e{}^{\sigma b} P_e^{1-\sigma b} + \alpha_g{}^{\sigma b} P_g{}^{1-\sigma b} \tag{10}$$

Suppliers in every sector maximise their profit under perfect competition and produce under linearly decreasing returns:

$$\underset{c}{Max} \quad \pi_c = P_c \cdot c - \left(\gamma_c \cdot c + \frac{\delta_c}{2} c^2 \right) \tag{11}$$

The first order condition leads to the supply function:

$$c_s = \frac{P_c - \gamma_c}{\delta_c} \tag{12}$$

$$\underset{e}{Max} \quad \pi_e = P_e \cdot e - \left(\gamma_e \cdot e + \frac{\delta_e}{2} e^2 \right) \tag{13}$$

$$e_s = \frac{P_e - \gamma_e}{\delta_e} \tag{14}$$

$$\underset{g}{Max} \quad \pi_g = P_g \cdot g - \left(\gamma_g \cdot g + \frac{\delta_g}{2} g^2 \right) \tag{15}$$

$$g_s = \frac{P_g - \gamma_g}{\delta_g} \tag{16}$$

The cost incurred by consumers to get a given utility from consumption $\overline{U}$ is:

$$CC = P_e \cdot e + P_g \cdot g + P_c \cdot c = P_{ES} \cdot ES + P_c \cdot c = P_U \cdot \bar{U} \quad (17)$$

And the total cost is

$$TC = CC - \left(\pi_e + \pi_g + \pi_c\right) \quad (18)$$

2.2. Calibration of the parameters

Calibration is done in order to represent roughly the French residential sector. In the next two sections, we present the results for different values of the elasticities of substitution σ_a, σ_b. We calibrate the other parameters $\alpha_j, j \in \{c, g, e, ES\}, \gamma_i, \delta_i, i \in \{c, g, e\}$ in order to be consistent with the following data and assumptions:

a. The budget share of residential energy in households' consumption in France is around 4% (from Besson, 2008).

b. Based on discussion with technical experts, we assume that the budget share of *g* is half that of *e.* Unfortunately, there is no data on the budget share of energy-saving goods and services which are embedded in other goods. For example, there is little data on the supplemental cost of an energy-efficient appliance compared to an energy-inefficient one.

c. The gross profit ratio (gross operating surplus/value added) of energy producers in France in 2004 is around 50% (INSEE, 2007).

d. The gross profit ratio in France in average in 2004 is around 30% (INSEE, 2007). We assume that this ratio applies to firms in the *g* and *c* sectors.

Without loss of generality we set every price (in business-as-usual) equal to one and U = 10. From assumptions a and b, for a given value of σ_a and σ_b we can then calibrate the α_j. For example, setting $\sigma_a = 0.5$ and $\sigma_b = 1$ leads to: $\alpha_c = 0.8836$, $\alpha_{ES} = 0.0036$, $\alpha_e = 0.666667$, $\alpha_g = 0.333333$. Combining these results with assumptions c and d, we get $\gamma_e = 0$, $\gamma_g = \gamma_c = 0.4$, $\delta_e = 2.5$, $\delta_g = 3$ and $\delta_c = 0.0638298$.

We then numerically solve the eight supply and demand equations (4-8), (12), (14) and (16), which provide the four quantities *c*, *e*, *g* and *ES.*

To compute the equilibrium with an energy saving policy, we let *e* exogenous and modify some of the above equations as described in sections 2.3 to 2.8 below. We are thus able to compare the outcome of these policy instruments for a given level of energy saving. We implicitly assume that an excessive energy use entails external costs (air pollution, climate change, threats on supply security…), justifying an energy-saving policy, but we do not model this part of the issue. In other words, we set a cost-efficiency framework, not a cost-benefit one.

2.3. White certificates with a target as a percentage of energy sold ($WC_{\%}$)

Under this policy instrument, energy suppliers have to generate a given amount of energy efficiency measures, in a quantity $w.e$ proportional to the quantity of energy they sell, e. To fulfil this obligation, we assume that they can only subsidise energy-saving goods and services g. For each unit of g they subsidise, they get one white certificate. We assume that firms comply with this obligation, so the quantity of white certificates equals the aggregate target. Since we model only one type of energy- saving goods and services, it is impossible to distinguish business-as-usual purchase of g from additional energy efficiency measures[4]. We thus assume that every sale of g is subsidised.

A new equation appears, the energy-efficiency constraint put by public authorities on energy suppliers:

$$w \cdot e \leq g \qquad (19_{\text{WC\%}})$$

We assume that this constraint is binding. Otherwise, the price of white certificates would drop to zero and the policy would have no effect at all.

Neither consumers nor suppliers of composite goods are directly affected; hence the first twelve equations do not change. Equations (17-18) do not change either.

Equations (13) to (16) are modified as below:

$$\underset{e}{Max} \quad \pi_e = \left(P_e - P_w.w\right)e - \left(\gamma_e.e + \frac{\delta_e}{2}e^2\right) \qquad (13_{\text{WC\%}})$$

$$e_s = \frac{P_e - P_w.w - \gamma_e}{\delta_e} \qquad (14_{\text{WC\%}})$$

$$\underset{g}{Max} \quad \pi_g = \left(P_g + P_w\right)g - \left(\gamma_g.g + \frac{\delta_g}{2}g^2\right) \qquad (15_{\text{WC\%}})$$

$$g_s = \frac{P_g + P_w - \gamma_g}{\delta_g} \qquad (16_{\text{WC\%}})$$

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[4] In the real world, such a distinction is very costly. Accordingly, the regulator of the UK scheme recognises that "the target included business as usual energy efficiency activity" (UK Ofgem, 2005, p. 5).

where P_w is the price of a white certificate.

Compared to the business-as-usual, we now have one more equation, one less variable (e), and two more variables: P_W and w.

2.4. White certificates with an absolute target (WC_A)

The only difference with $WC_{\%}$ is that energy suppliers now have to deliver white certificates in a fixed quantity W meaning that each producer's target is defined independently of this producer's current and future decisions[5]. The target may for instance be proportional to the historical output of each producer – but not to its current output, otherwise we are back to $WC_{\%}$.

We will see in section 3 that this distinction has important consequences. The equilibrium on the white certificates market becomes:

$$W = g \tag{19 WCA}$$

where W is the energy producer's target.

Here again, neither consumers nor suppliers of composite goods are not directly affected, hence neither the first twelve equations nor equations (17-18) change.

Equations (13) to (16) are modified as below:

$$\underset{e}{Max} \quad \pi_e = P_e.e - P_w.W - \left(\gamma_e.e + \frac{\delta_e}{2} e^2 \right) \tag{13 WCA}$$

$$e_s = \frac{P_e - \gamma_e}{\delta_e} \tag{14 WCA}$$

$$\underset{g}{Max} \quad \pi_g = \left(P_g + P_w \right) g - \left(\gamma_g.g + \frac{\delta_g}{2} g^2 \right) \tag{15 WCA}$$

$$g_s = \frac{P_g + P_w - \gamma_g}{\delta_g} \tag{16 WCA}$$

Compared to the business-as-usual, we now have one more equation, one less variable (e), and two more variables: P_W and W.

[5] The existing TWC schemes are somewhat intermediary. In the UK, targets are a function of the number of customers, a case which would require a more complex model to be explicitly analysed. In France and Italy, they are proportional to energy sales in the last year for which data were available when targets were fixed. An updating is likely at the end of the every period (three years in France, five in Italy).

2.5. Tax rebated lump-sum to consumers (T_H)[6]

Under this policy instrument, energy produced is taxed at a rate t and receipts from the tax are given lump-sum to consumers. A new equation describes the public budget balance:

$$t \cdot e = LS \qquad (19_{\text{TH}})$$

where LS is the lump-sum subsidy received by the representative consumer.

Compared to the initial model, equations (13), (14) and (18) are modified as below[7]:

$$\underset{e}{Max} \quad \pi_e = (P_e - t)e - \left(\gamma_e \cdot e + \frac{\delta_e}{2} e^2\right) \qquad (13_{\text{TH}})$$

$$e_s = \frac{P_e - t - \gamma_e}{\delta_e} \qquad (14_{\text{TH}})$$

$$TC = CC - \left(\pi_e + \pi_g + \pi_c\right) - LS \qquad (18_{\text{TH}})$$

Compared to the business-as-usual, we now have one more equation, one less variable (e), and two more variables: t and LS.

2.6. Tax rebated lump-sum to energy suppliers (T_E)[8]

The only difference with the previous policy instrument is that the receipts from the tax are now rebated (lump-sum) to energy suppliers and not to consumers. Again, a new equation describes the public budget balance:

$$t \cdot e = LS \qquad (19_{\text{TE}})$$

Compared to the initial model, only equations (13) and (14) are modified, as below:

$$\underset{e}{Max} \quad \pi_e = (P_e - t)e - \left(\gamma_e \cdot e + \frac{\delta_e}{2} e^2\right) + LS \qquad (13_{\text{TE}})$$

$$e_s = \frac{P_e - t - \gamma_e}{\delta_e} \qquad (14_{\text{TE}})$$

Compared to the business-as-usual, we now have one more equation, one less variable (e), and two more variables: t and LS.

---

[6] Since we do not model uncertainty on costs nor market power, this policy instrument is equivalent to a tradable permits scheme imposed to energy suppliers, with permits auctioned and receipts transferred to consumers. However, in general, tradable permits cover noxious emissions, not energy sold.

[7] Note that under the taxes and the subsidy P_e and P_g are the prices paid *by the consumers*.

2.7. Subsidy on energy-efficient goods and services

Under this policy instrument, the production of g is subsidised at a rate s and the cost of the subsidy is covered by a lump-sum tax on consumers. A new equation describes the public budget balance:

$$s \cdot g = LS \qquad (19_S)$$

where LS is the lump-sum tax paid by the representative consumer.

Compared to the initial model, equations (15), (16) and (18) are modified as below:

$$\underset{g}{Max} \quad \pi_g = \left(P_g + S\right) g - \left(\gamma_g . g + \frac{\delta_g}{2} g^2\right) \qquad (15_S)$$

$$g_s = \frac{P_g + S - \gamma_g}{\delta_g} \qquad (16_S)$$

$$TC = CC - \left(\pi_e + \pi_g + \pi_c\right) + LS \qquad (18_S)$$

Compared to the initial model, we now have one more equation, one less variable (e), and two more variables: s and LS.

2.8. Energy-efficiency regulation (R)

Consumers still minimise their cost according to equations (1-4) but now subject to a new constraint:

$$\frac{ES}{e} \geq r \qquad (19_R)$$

Which we assume binding. This is a classical and straightforward way of modelling energy efficiency regulation; cf. Wirl (1989)[9].

Assuming that both constraints (4) and (19_R) are binding, equations (7) and (8) become:

$$e_d = \frac{ES}{r} \qquad (7_R)$$

---

[8] In our model, this would be equivalent to a tradable permits scheme with permits grandfathered, i.e., distributed for free to energy suppliers.

[9] In the transport sector, the US CAFÉ (Corporate average fleet efficiency) regulation for cars and light trucks is expressed in this way, ES being a number of miles and e being expressed in gallons of gasoline. Japan has a similar (although more ambitious) regulation and in the European Union, such a regulation has been recently proposed by the Commission.

In the building sector, many thermal regulations are also expressed in such a way, ES being a number of m² heated at a certain temperature, for a given external temperature.

$$g_d = ES\left(\frac{1-\alpha_e \cdot r^{\frac{1-\sigma b}{\sigma b}}}{\alpha_g}\right)^{\frac{\sigma b}{\sigma b-1}} \qquad (8_{\text{R}})$$

Compared to the business-as-usual, we now have one less variable (*e*), one more variable (*r*) and the same number of equations.

3. Numerical results

For each policy instrument, we solve the model for a given level of energy consumption. We choose an energy-saving target of 2% compared to business-as-usual, a figure in line with the existing TWC schemes (cf. section 1 above). It turns out that the evolution of every variable is monotonous with the energy-saving target so contrarily to Quirion (2005) we do not present the results for different levels of energy-savings. Instead, we present the results for different values of σ_a and σ_b. More precisely, for every variable we present the results for $\sigma_a = 0.5$ and different values of σ_b as well as the results for different values of σ_a and for $\sigma_b \approx 1$ [10]. The choice of $\sigma_a = 0.5$ and $\sigma_b \approx 1$ as benchmark values is in line with the CGE literature, cf. Gerlagh and Kuik (2007, p. 9).

3.1. Total costs and quantities

The first row of Figure 3 displays the increase in total cost compared to the business-as-usual equilibrium (note that the scale of the y-axis for TC is logarithmic). It turns out that for $\sigma_a = 0$ every policy instrument entails the same overall cost. However as soon as $\sigma_a > 0$ the two taxes entail the lowest overall cost, followed by $WC_{\%}$ and R, whereas WC_A and S entail the highest cost. The explanation is the following. To reach a given level of energy savings at the lowest aggregate cost, it is optimal both to substitute *g* to *e*, i.e., to increase energy efficiency, and to reduce the level of energy service *ES*, i.e., to progress towards sufficiency[11]. As is apparent from the second row of Figure 3, all instruments lead to substitute *g* for *e*, but (third row) only the taxes lead to a decrease in *ES*. The other instruments induce an increase in ES, either moderate ($WC_{\%}$, R) or significant (WC_A, S)[12]. In other terms, they generate a rebound effect: a part of the

[10] The CES function is not defined for a unitary elasticity of substitution – in this case it tends to a Cobb-Douglas function – so we take the closest to one value that was numerically feasible.

[11] On this way of framing the issue, cf. Salomon et al. (2005) and Alcott (2008).

[12] Note that a similar issue arises in the analysis of allocation rules for CO_2 allowances: under an output-based allocation rule, too much CO2-intensive goods are produced compared to the optimum, while auctioning and lump-

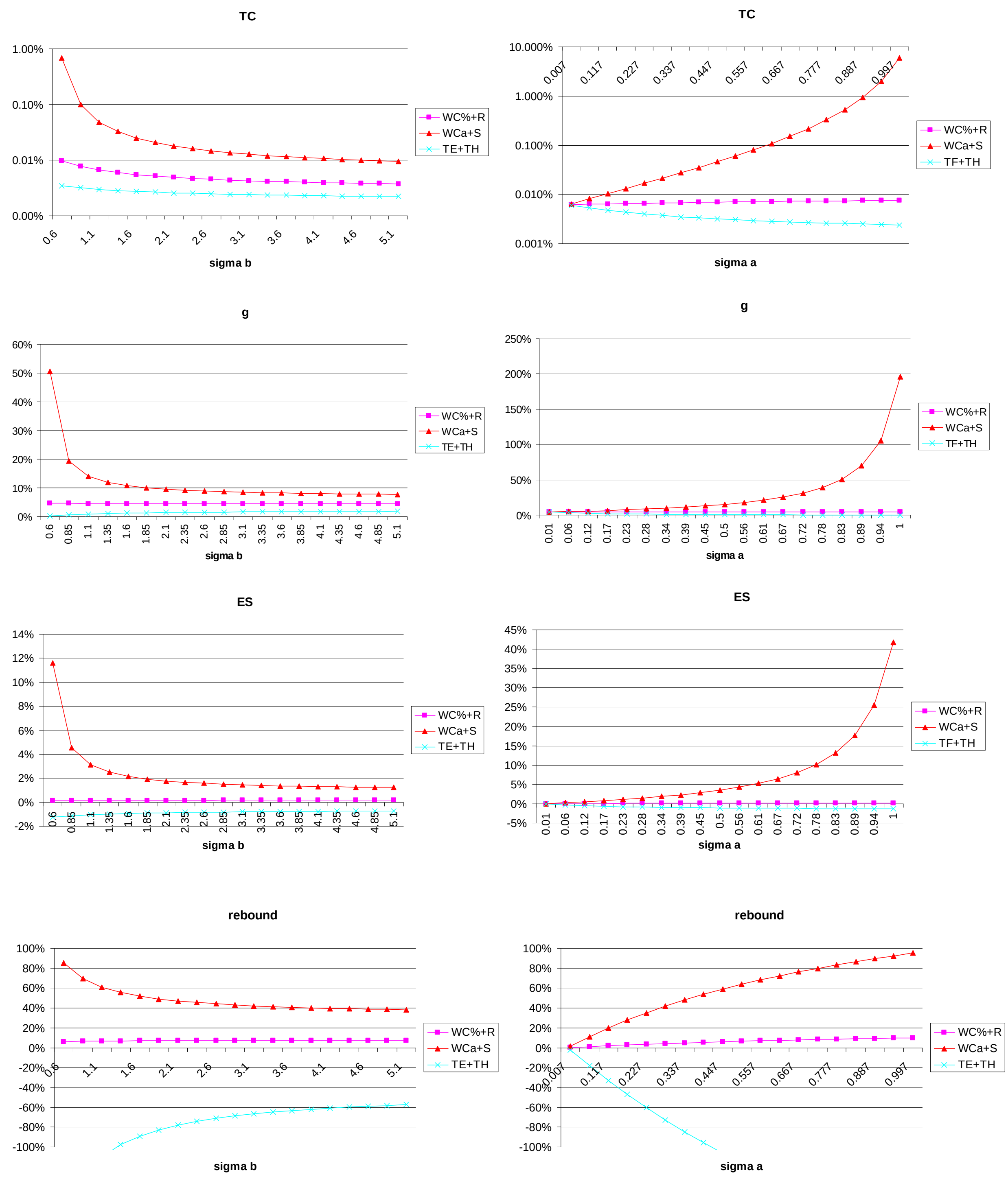
increase in energy efficiency (SE/e) is "lost" because of an increase in ES. To compensate for this rebound effect, the substitution of *g* for *e* has to be higher, especially for WC_A and S. The lower row of Figure 3 presents the rebound ratio, defined as $\frac{\Delta ES/ES}{\Delta ES/ES - \Delta e/e}$. This ratio indicates the share of energy savings that is "lost" because of the increase in ES (if any). As the value of σ_a tends towards that of σ_b, this ratio also tends to 100% with S or WC_A whereas it only tends to 10% with R or $WC_{\%}$.

Quantitatively, the difference in total cost across instruments is massive. For example, for the benchmark case with $\sigma_a = 0.5$ and $\sigma_b \approx 1$, the cost of reaching the energy-savings target is 20 times higher with WC_A and S than with taxes and 9 times more costly than with WC_B and R. Even with $\sigma_a = 0.1$ and $\sigma_b \approx 1$, WC_A and S are twice more costly than taxes.

sum allocation lead to the optimal production, at least in a closed economy with perfect competition (Quirion, 2007).

Figure 3. Impact of a 2% energy-saving target on total cost and on quantities.

Left panels: $\sigma_a = 0.5$. Right panels: $\sigma_b \approx 1$



3.2. Consumers' prices

As indicated by the first row of figure 4, the evolution of the consumers' energy price is much contrasted: it goes down with WC_A, S and R; and up with T_E, T_H and $WC_{\%}$, more sharply with taxes than with $WC_{\%}$. These evolutions may be explained as follows. Under all policy instruments, the decrease in energy consumption makes the energy price go downward, since the energy supply curve is upward-slopping. Under WC_A, S and R, this is the only influence on energy price. However, under both taxes, the energy price rises since suppliers pass the tax on to consumers. The same stands under $WC_{\%}$: since suppliers must generate more certificates if they increase their production, the certificates' cost is a part of their marginal cost (cf. eq. $14_{WC\%}$ above), hence of energy price. However the rise in energy price is lower under $WC_{\%}$ than under the taxes because under the former, substitution of g for e from two channels: the decrease in P_g and the rise in P_e, thus for a given level of energy saving, the evolution of each of these prices may be lower than if only one channel was used.

$WC_{\%}$ and WC_A have a contrasted impact on P_e: under WC_A, since every supplier's target is exogenous, the suppliers do not include the certificates' cost in their marginal cost (cf. eq. 14_{WCA} above[13]). This distinction has important distributional and efficiency consequences. In particular, since WC_A decreases P_g without raising P_e, P_{ES} decreases so ES increases; this rebound effect explains why WC_A is so costly (cf. section 3.1 above).

Of course, the higher σ_b, i.e., the more substitutable e and g, the lower the increase in P_e necessary to get a given level of energy savings under T_E, T_H and $WC_{\%}$. Also, the higher σ_a, i.e., the more substitutable ES and c, the lower the increase in P_e necessary to get a given level of energy savings under T_E and T_H. Yet the opposite is true for $WC_{\%}$, because the higher σ_a, the higher the rebound effect.

The second row of figure 4 displays the impact on P_g, the consumers' price of g. It rises with R, T_F and T_H because the supply curve is upward-slopping and demand for g rises. Under S, WC_A and $WC_{\%}$, it goes down since this good is subsidised, but less so under $WC_{\%}$ because in this case, as we have just seen, a part of the energy savings comes from the increase in P_e. Of course, for S, WC_A and $WC_{\%}$, the higher σ_b, the lower the decrease in P_g necessary to get a given level of energy savings. However, the higher σ_a, the higher the decrease in P_g necessary, because in this case the rebound effect is higher.

The price-index of the energy service P_{ES} (not shown here) is a combination of P_e and P_g hence it stems from the above-mentioned evolutions. It increases under the two taxes, decreases sharply under WC_A and S and is slightly reduced under $WC_{\%}$ and R. Finally P_c (not shown here)

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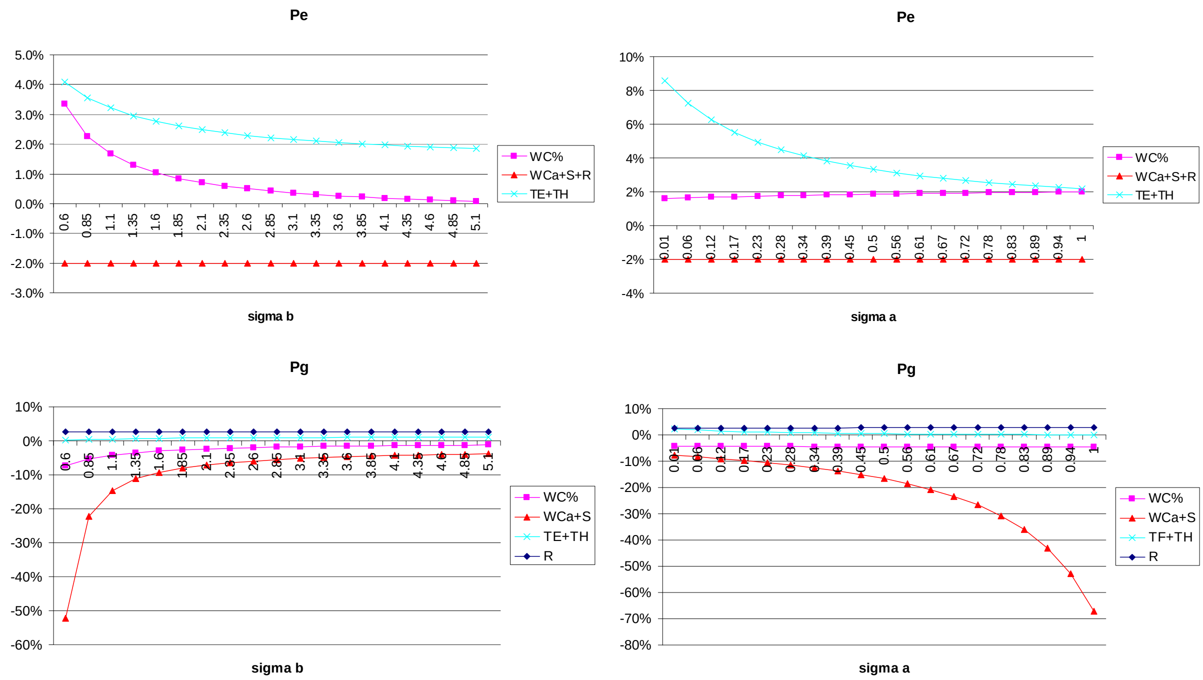
[13] This conclusion stems for our short-term, perfect competition model, but it would not necessarily stand in the longer run, especially in a more complex model with imperfect competition, free entry and exit.

is almost unaffected; it increases slightly under the taxes because consumers substitute *c* for *ES* and the supply curve is upward slopping; and vice-versa for WC_A and S.

Figure 4. Impact of a 2% energy-saving target on P_e and P_g.

Left panels: $\sigma_a = 0.5$. Right panels: $\sigma_b \approx 1$



3.3. Distributional consequences

The upper-left panel of figure 5 displays energy suppliers' profit, which drops in the same proportion with all policy instruments except WC_A and T_E. Under WC_A, it decreases much more since energy suppliers pay the cost of white certificates while, as already explained, they do not pass this cost on to consumers, due to the lump-sum nature of their targets. Note that for a low σ_b or a high σ_a, profit can become negative: suppliers still make some money by selling energy but this not enough to pay the cost of white certificates[14]. Under T_E, it rises since the energy price increases despite energy suppliers receiving a rebate: since this rebate is lump-sum, it does not influence their pricing behaviour, based on marginal cost. Energy suppliers thus benefit from a windfall profit under this policy instrument, as they do under the EU ETS (Sijm et al., 2006).

[14] In the real world, some firms would most likely exit the market, pushing up the energy price. Alternatively, governments may put a cap on the price of white certificates, which they did in France.

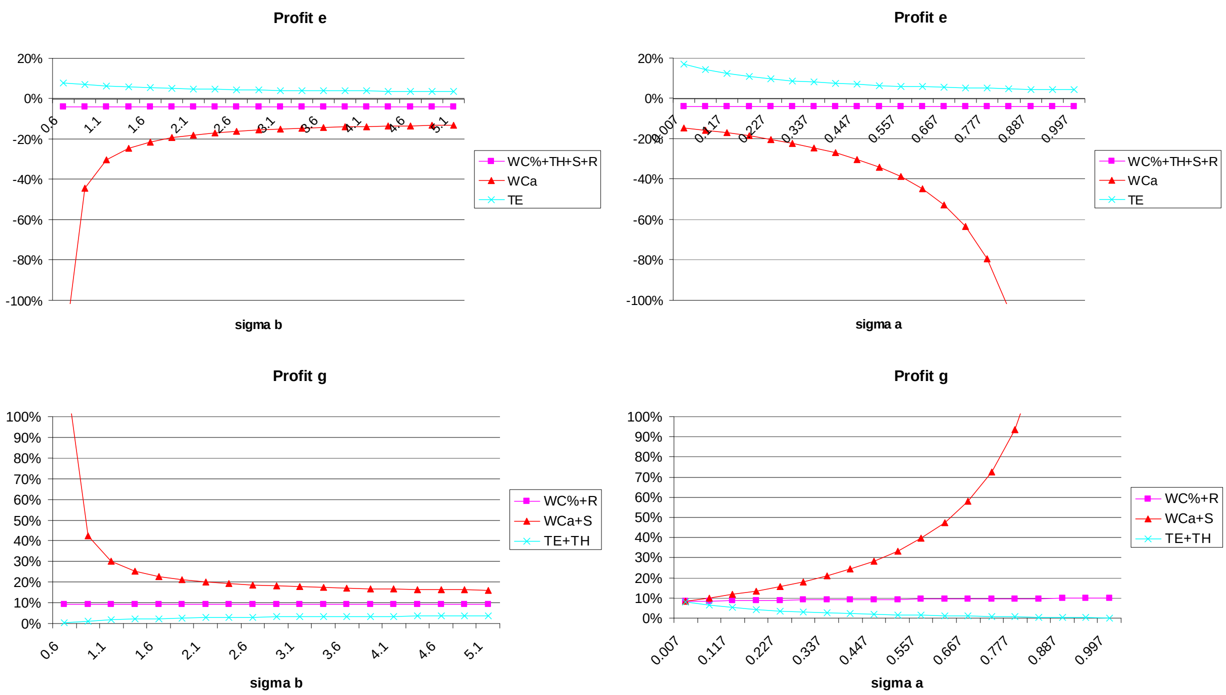
The profit of energy-saving goods and service (g) producers' rises with every instrument. The increase is identical for $\sigma_a \approx 0$, otherwise it is proportional to the rise in demand for g, i.e., higher for WC_A and S and lower for the taxes.

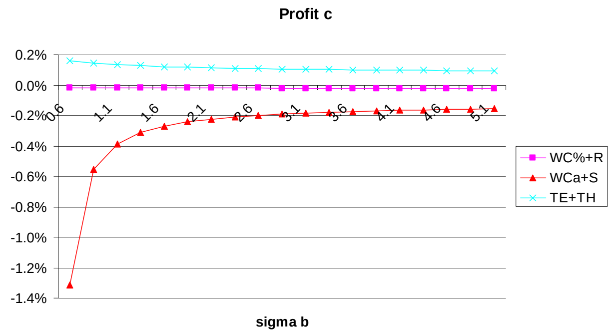
The profit of composite goods (c) producers also evolves proportionally to the demand for c, but with much more moderate changes.

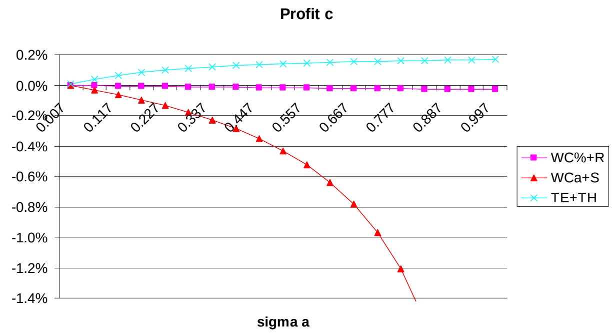
The last row of Figure 5 displays the cost for consumers CC, which is the cost of purchasing the goods allowing a utility from consumption $\bar{U}$ plus LS with S (since the subsidy is financed by a lump-sum tax on households) or minus LS with T_H (since the receipts from the tax on energy are rebated lump-sum to households). Consumers are net winners under WC_A and net losers under T_E. The impact of these instruments on CC is thus symmetric to their impact on π_g. Consumers are pretty much unaffected under $WC_{\%}$, T_H and R. So are they with S if σ_a is low enough and/or if σ_b is high enough, but otherwise the cost to consumers is relatively high. These are also the parameters for which S entails the highest total cost; in this case, a very high subsidy rate has to be paid, hence consumers have to pay a very high lump-sum tax.

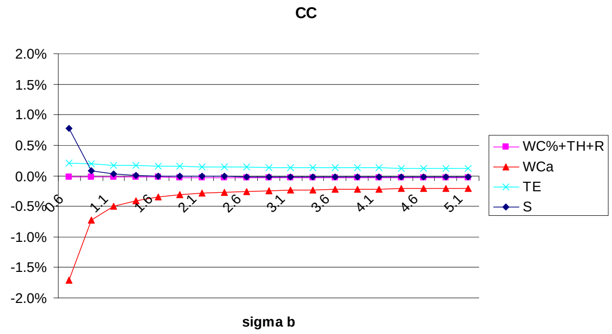
Figure 5. Impact of a 2% energy-saving target on the components of total cost

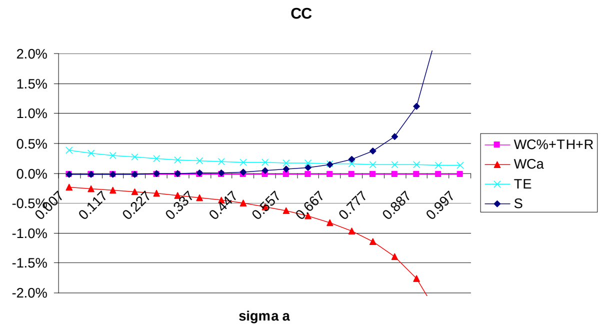
Left panels: $\sigma_a = 0.5$. Right panels: $\sigma_b \approx 1$











4. Discussion

4.1. Where to apply which policy instrument?

We have seen that the relative cost of policy instruments depends crucially on the value of σ_a. If this value is close to zero, there is little rebound effect and every instrument entails the same overall cost, but if it is high, there is a large rebound and taxes are much more cost-efficient than $WC_{\%}$ and R and even more so than WC_A and S. Many empirical estimates of the rebound effect have been published. Greening et al., 2000 performed a review of over 75 estimates and conclude that no significant rebound exist for white appliances, and only a limited one for residential lighting. The cost penalty (compared to taxes) associated with $WC_{\%}$ or R is thus probably limited for these applications. On the opposite a larger rebound seems to exist for automobile transport, space cooling, space heating and water heating, hence the cost difference between taxes and the other policy instruments should be higher.

4.2. Equity and political acceptability

Although the taxes entail the lowest aggregate cost, they may be politically more difficult to implement economists than other instruments because they lead to a higher (and highly visible) increase in energy price. WC_A causes a significant drop in energy suppliers' profit so the latter are likely to lobby against this instrument.

$WC_{\%}$, R and S have politically the advantage of transferring a part of the cost on the producers of the composite good, a heterogeneous group unlikely to engage in the policy process on such an issue since energy is not a part of their business and since they are only marginally affected. In addition, they increase π_g significantly (10% at least), so producers of energy-saving goods and services may form an influent lobby group in favour of such policies. This may explain why regulations and subsidies form the bulk of energy-saving policy instruments in the real world and why many countries have launched, or are considering[15], a TWC Scheme.

4.3. Issues not included in the model

Equalisation of the marginal cost of energy saving

TWC schemes, just like taxes and tradable allowances, allow an equalisation of the marginal cost of energy savings among energy suppliers under certain conditions. This is the very rationale for implementing tradable certificates rather than rigid energy savings targets. On the opposite, rigid energy-efficiency regulations do not provide such flexibility. For example, it may be cost efficient to keep appliances, light bulbs and dwellings with low energy efficiency where they are scarcely used (e.g. incandescent light bulbs in toilets, cheap insulation in second homes…). A rigid set of regulation would rule out this possibility. Yet more flexible forms of regulation exist: the US CAFÉ regulation does not limit the fuel consumption of every car but of the average of the cars sold by each manufacturer. Proposals go around in the US to add flexibility among manufacturers, through tradable allowances. To sum up, equalisation of the marginal cost of energy saving is an advantage of TWC schemes over rigid regulation, but not necessarily over more flexible forms of regulation.

The "energy-efficiency gap"

The "energy-efficiency gap" refers to the fact that many opportunities to save energy are not implemented by consumers although the decrease in fuel cost would outweigh the cost of the energy efficiency investment according to standard cost-benefit analysis[16]. This raises some doubts on the efficiency of energy taxes: if consumers take little account of energy price in their behaviour, raising this price is unlikely to cut energy consumption sharply. On the opposite,

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[15] According to EuroWhiteCert (2007) Denmark and the Netherlands consider implementing such a system.

[16] In the model we assume that economic agents (in particular energy suppliers and consumers) are perfectly rational and that the information provided is perfect. As a consequence, we rule out the energy-efficiency gap, while this gap may be seen as one of the main reasons for implementing energy-efficiency policies. Yet various economic mechanisms may explain it and no theoretical model can represent all of them. Hence, choosing a model featuring one of the economic mechanisms behind the energy-efficiency gap appears certainly desirable, but only as a second step, once results from a more canonical model with perfect rationality and information are available.

regulation, if strictly implemented, may be economically efficient by forcing consumers to implement energy-efficiency measures that are financially profitable but bypassed in business-as-usual.

Would TWC schemes help mobilising the energy-efficiency gap? The answer obviously depends on what explains this gap. Many explanations have been put forward (cf. Jaffe and Stavins, 1994, and Sorrell et al., 2004). We will not restate them here but simply stress that TWC schemes may help alleviating some (but not all) of them. Indeed several explanations of the energy-efficiency gap point out that some consumers give more importance to investment costs than to energy costs, for various reasons: limited access to credit due to asymmetric information by lenders on the credit market, split incentives to save energy, e.g., in collective housing or commercial centres, rigid separation between investment and operating budget in organisations…

By reducing the cost of energy-efficient capital goods for the consumers, TWC schemes may thus help mobilising a part of the energy-efficiency gap more easily than taxes. However this intuition should be checked in a formal model featuring some factors which explain the energy-efficiency gap, including those mentioned above. We leave this for future research.

Transaction costs

In the case of TWC schemes, more precisely of the British EEC, Mundaca (2007) identified and quantified transaction costs through a questionnaire distributed to energy suppliers and through interviews. He found out that transaction costs include search for information, persuasion of customers, negotiation with business partners, measurement and verification activities and due accreditation of savings. Mundaca estimated that transaction costs represented 8% to 12% of investment costs for lighting measures and 24% to 36% for insulation measures.

These figures are quite significant and most likely higher than transaction costs that could be generated with taxes or regulations.

5. Conclusion

Although simple and transparent, our partial equilibrium model allows us to compare in a single framework tradable white certificate schemes with the main existing policy instruments for energy efficiency: energy taxes, subsidies on energy-saving goods and regulations setting a minimum level of energy efficiency. We highlight the importance of the rebound effect and more generally of the impact of the policy instruments on the consumption of energy service. We provide three major conclusions.

First, if a tradable white certificate scheme is to be implemented, a generally neglected but important issue is whether the energy-efficiency target imposed to every energy supplier is in proportion of the current quantity of energy sold by this firm or whether this target is disconnected from the firm's current decisions. We argue for the former option, which reduces the distributive impact of the policy, the rebound effect and the overall cost.

Second, a tradable white certificate scheme (with targets in proportion of the current quantity of energy sold by this firm) entails a higher overall cost than an energy tax but less than a subsidy on energy-saving goods. The difference in cost among policy instruments is low for energy services with a low elasticity of demand, such as white appliances, but may be high for energy services with a higher elasticity of demand, such as automobile transportation, space heating, water heating or space cooling.

Third, a tradable white certificate scheme (with the above precision) may be politically easier to implement than an energy tax because it entails little wealth transfers.

We also discuss informally some mechanisms not included in our models. Firstly, compared to rigid standards, a TWC scheme has the advantage of equalising the marginal cost of energy saving, but generate more transaction costs. Secondly, compared to taxes, they also generate more transaction costs but they are probably more able to address the energy-efficiency gap.

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Appendix 1. List of variables and parameters

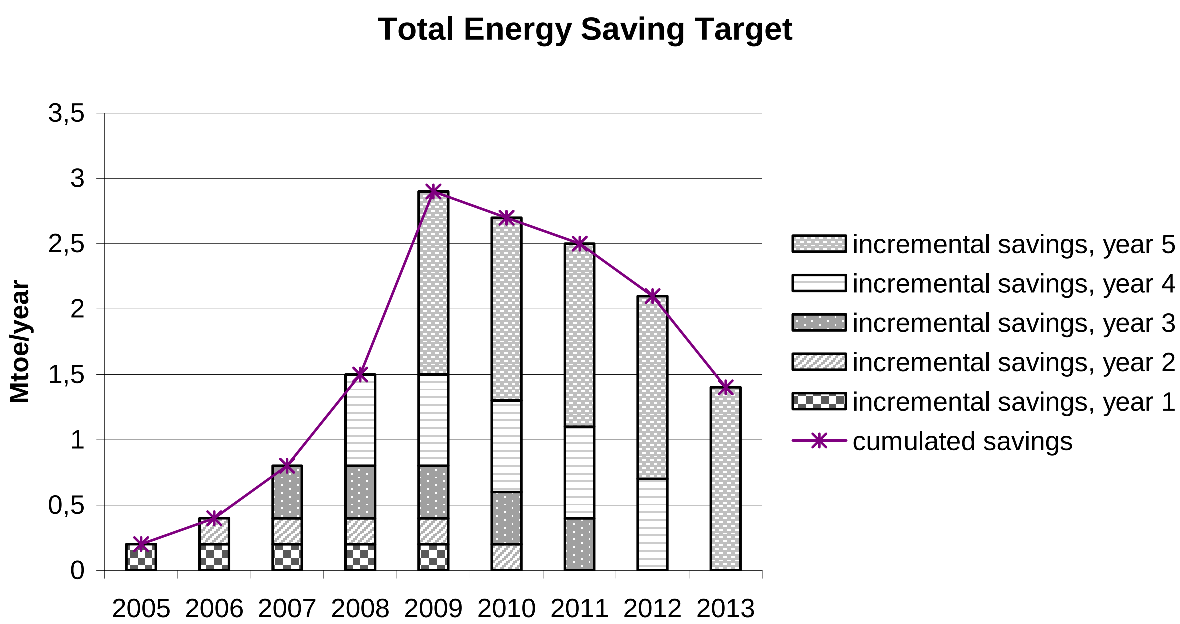
Variable	Domain	Signification	policy instrument
e	> 0	Quantity of energy	All
g	> 0	Quantity of energy-saving goods and services	"
c	> 0	Quantity of composite good	"
ES	> 0	Level of energy service	"
$P_i, i \in \{e, g, c, ES\}$	> 0	Price of good *i*	"
w	≥ 0	Energy savings target for each unit of energy sold	$WC_{\%}$
W	≥ 0	Energy savings target	WC_A
P_w	≥ 0	Price of tradable white certificates	$WC_{\%}$, WC_A
t	≥ 0	Tax rate	TH,T_E
s	≥ 0	Subsidy rate	S
LS	≥ 0	Lump-sum tax/subsidy/rebate	TH,T_E,S
r	≥ 0	Minimum ratio of energy efficiency *ES*/*e*	R

Parameter	Domain	Signification
$\alpha_i, i \in \{e, g, c\}$	$\in]0,1[$	Share parameter of good *i* in consumers' utility
$\gamma_i, i \in \{e, g, c\}$	≥ 0	Intercept of suppliers' marginal production cost curve
$\delta_i, i \in \{e, g, c\}$	≥ 0	Slope of suppliers' marginal production cost curve
σ_a	≥ 0	Elasticity of substitution in the utility function (upper level)
σ_b	> 0	Elasticity of substitution in the utility function (lower level)

Appendix 2. Comparison of national targets

We compare national targets by formulating them in the same way: in *TWh* of *final* energy savings, *cumulated* over the measures lifetime and *discounted*. This is actually the way the British and French targets are formulated (with close discount rates of respectively 3.5% and 4%). The difficulty is thus to convert into this way the Italian target, originally formulated in ton of oil equivalent (toe) of primary energy.

For that purpose, we interpret the Italian target as follows (Pavan, 2005):



The undiscounted cumulated savings are the area under the curve, which is equal to five times the amount of savings in year 2009 (2.9 Mtoe). Since we use a 4% discount rate, the multiplying factor is not 5 but actually 4.63. Since this figure is in primary energy, we multiply it by 0.8[17] to convert it in final energy and by 11.63 to convert it in TWh.

We thus have: 2.9 * 4.63 * 0.8 * 11.63 = 125 TWh.

We then divide every national absolute target by the scheme's length and formulate them in "annual TWh". This unit has no physical meaning but allows us to compare the *absolute* constraint levels in a standardised way. Eventually we compare these amounts to the national final energy consumption in order to have an idea of the *relative* constraint of each scheme, using the IEA statistics of year 2005.

[17] This is approximately the ratio between final consumption (148.07 Mtoe according to IEA) and primary consumption (186.8 Mtoe according to Eurostat) in Italy in 2005.

	UK 02-05	UK 05-08	Italy 05-09	France 06-09
Quantitative target (standardised TWh)	81 TWh[18]	130 TWh	125 TWh	54 TWh
Scheme length	3 years	3 years	5 years	3 years
Annual constraint	**27 TWh/year**	**43 TWh/year**	**25 TWh/year**	**18 TWh/year**
Annual final energy consumption in 2005	1886 TWh/year	1886 TWh/year	1722 TWh/year	2052 TWh/year
Target in % of final energy consumption	**1.43%**	**2.28%**	**1.45%**	**0.88%**

The results of this standardization exercise must be interpreted carefully since similar measures do not generate the same amount of credits in every country. In particular the energy savings generated by insulation measures are cumulated over 8 years in Italy, 35 in France and 40 in the UK. Hence our comparison probably underestimates the Italian target compared to the others.

[18] The original figure is 62 TWh with a 6% discount rate; it amounts to 81 TWh with a 3.5% discount rate (Defra, 2004, p.4)

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