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The Tradable White Certificates scheme: An economic analysis of energy savings and rebound effects.

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***Abstract*—In order to improve energy efficiency, several developed countries have implemented an innovative market mechanism: The tradable white certificates (TWC) scheme. This instrument could unlock energy saving potentials and actors that are not currently unlocked by other traditional instruments. However, as well as all other instruments for energy efficiency improvement, the TWC can stimulate the so-called ”rebound effect”. This effect occurs when some or all the expected energy reductions, as a result of energy efficiency improvements, may be compensated by energy increase because of household behavioral changes.**
The focus of this paper is to evaluate the effectiveness of the TWC instrument. The investigation of this issue requires an economic model to compare the impact of introducing the TWC scheme on energy savings as well as on the magnitude of the rebound effect to business-as-usual situation.
The results shows that the tradable white certificates scheme can have an additional advantage in terms of energy savings and rebound effects reduction.

***Index Terms*—Energy efficiency, Tradable white certificates, Energy savings, Rebound effect.**

I. Introduction

In the last years, several developed countries such as UK, France, Italy, Denmark, Netherlands, Belgium and Poland have implemented a white certificate scheme as a new instrument based on the market approach. Compared to command and control policies (regulation, taxation, etc.), this system could unlock energy saving potentials and actors that are not currently unlocked by other instruments [1]-[6].
As shown in figure.1, the system is based on the implementation of a market and requires some key elements to be successful [7]:

- set a quantitative overall target in absolute terms or relative to energy consumption.
- determine the obligated participants of the trading scheme.
- establish regulation to translate the overall target into individual targets for the obligated parties.

Under TWC policy, Government sets an overall energy-saving target to be met by producers, suppliers or distributors of electricity, gas and oil within a given period. To meet their targets, obliged actors are required to undertake energy efficiency measures for the final user that are consistent with a pre-defined percentage of their annual energy deliverance. To reduce compliance costs, obligated parties have the option

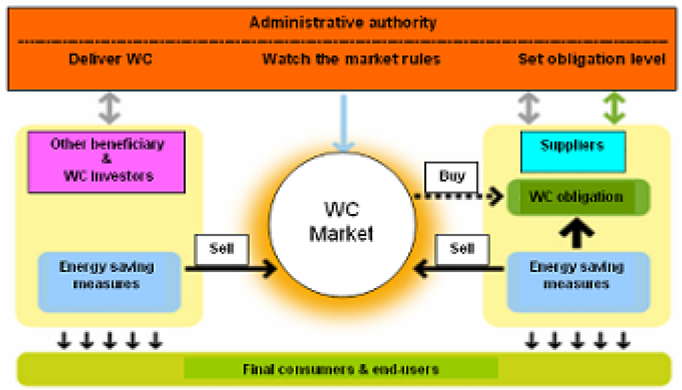

Fig. 1. The Tradable White Certificates scheme [9].

of trading certified energy saving. They can buy TWCs from other parties who over-fulfill their targets with unused energy efficiency surplus. Therefore, that it is more profitable to buy certificates on the market rather than to pay a penalty to the Government. Therefore, that it is more profitable to buy certificates on the market rather than to pay a penalty to the Government [8]. Individual targets imposed on obliged parties can be expressed either in absolute terms or relative to their energy sales. According to Reference[10], we recall briefly some elements:

- The tradable white certificates TWC scheme is an interesting policy instrument for saving energy.
- Compared to tradable white certificates with absolute target TWC_{VA}, the instrument expressed as a pourcentage of energy sales $TWC_{\%}$ presents a further advantage in terms of equity and acceptability, since energy suppliers cover the certificate cost with increasing their sales price to consumers.
- Taxes, standards and $TWC_{\%}$ have similar distributional impacts on the economic agents, but the last instrument is slighly superior in termes of energy savings.

The most critical issue is that energy policy instruments for energy efficiency can generate a pervert effect called the ”Rebound Effect”. References [11]-[18] show that energy reduction because of energy efficiency improvements is compensated by energy increase because of behavioral changes. Indeed, the eventual gains in energy efficiency will reduce

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energy service price and hence, energy consumption will rise and partially offset the initial expected reductions in energy consumption; this is the "rebound effect" or the "take-back effect".

The full rebound effect can be distinguished into three types of rebound effect: direct, indirect, and economy-wide:

- Direct rebound effect: An increase in consumption of a particular energy service lowers its the lower cost of use, and hence increases its energy consumption. This is caused by substitution effect and income effect.
- Indirect rebound effect: The lower effective price of the energy service enables increased household consumption of other goods and services that also require energy.
- Economy wide effect: The fall in service cost reduces the price of other intermediate and final goods and leads to faster economic growth which leads to increase the whole energy demand.

Reference [19] enhanced the analysis of reference [10] to highlight the importance of the rebound effect and more generally of the impact of policy instruments on energy service consumption. First, the authors supported their first funding regarding the superiority of $TWC_{\%}$ to TWC_{VA}, since the first form of the scheme reduces the distributive impact of the policy, the rebound effect and the overall cost. Second, they show that the size of the rebound effect relates to the magnitude of the overall cost which depends on the elasticity of substituting energy services demand. If this elasticity is high, $TWC_{\%}$ entails a higher overall cost and a large rebound effect than an energy tax, but less than a subsidy on energy-saving goods. However, if it is close to zero, there is a small rebound effect and every instrument entails the same overall cost.

Similar to reference [19] and referring to our previous theoretical account on the direct and indirect effect on household consumption (see reference [20]),we showed that size of the rebound effects strongly depends on the elasticity of substituting energy services.

In this paper, we use the methodology described in reference [20], since we consider behaviors and equilibrium results already found are similar to those of the BAU scenario. Next, we compare the impact of introducing the $TWC_{\%}$ scheme on energy savings as well as on the magnitude of the rebound effects to a BAU situation. Moreover, we show that the ability of $TWC_{\%}$ to reduce direct and indirect rebound effects depends on the magnitude of the variation in energy service prices.

In Section II, the short run rebound effects model provided by Reference [20] is strengthened by the introduction of $TWC_{\%}$ to obtain the model under white certificates. In Section III, we compare between the BAU and the $TWC_{\%}$ models in terms of energy savings and direct and indirect rebound effects. Finally, Section IV concludes the paper.

II. The model under white certificates

A. Consumer's behavior

Similar to Reference [20], the consumer is considered as a producer of two types of energy services, G and Q. Both have respectively P_G and P_Q prices. Under his budget constraint, the consumer maximizes the CES utility function $U(G, Q)$. The energy service G (resp Q) is produced by the consumer, through combining equipment g (resp q) and energy E_g (resp E_q) in a Cobb-Douglas production function.

Then, we consider that consumer purchases energy E, appliance g and appliance q at the respective prices P_E, P_g and P_q. The goods cannot be consumed infinitely due to the consumer's limited revenue$R$.

Resolution of the household maximization program in business-as- usual situation leads to the following energy and goods demands[1]:

$$E_g = \left(\frac{R}{P_E}\right)\left(\frac{\alpha\beta A}{\alpha+\beta A}\right) \tag{1}$$

$$E_q = \left(\frac{R}{P_E}\right)\left(\frac{\alpha\beta}{\alpha+\beta A}\right) \tag{2}$$

$$g = \left(\frac{R}{P_g}\right)\left(\frac{(1-\alpha)\beta A}{\alpha+\beta A}\right) \tag{3}$$

$$q = \left(\frac{R}{P_q}\right)\left(\frac{(1-\beta)\alpha}{\alpha+\beta A}\right) \tag{4}$$

Where A is expressed as:

$$A = \left[\frac{\alpha\theta}{\beta(1-\theta)}\right]^{\frac{1}{1+\rho}} \left[\frac{\left(\frac{1-\beta}{\beta}\frac{P_E}{P_q}\right)^{1-\beta}}{\left(\frac{1-\alpha}{\alpha}\frac{P_E}{P_g}\right)^{1-\alpha}}\right]^{\frac{\rho}{1+\rho}} \tag{5}$$

The total energy demand is:

$$E_d = (E_g + E_q)_d = \frac{R}{P_E}\left(\frac{\alpha\beta(A+1)}{\alpha+\beta A}\right) \tag{6}$$

Based on previous demand functions, the two energy services can be calculated as:

$$G = \left(\frac{R\alpha\beta A}{\alpha+\beta A}\right)\left(\frac{1}{P_E}\right)^{\alpha}\left(\frac{1}{P_g}\right)^{1-\alpha}\left(\frac{1-\alpha}{\alpha}\right)^{1-\alpha} \tag{7}$$

$$Q = \left(\frac{R\alpha\beta}{\alpha+\beta A}\right)\left(\frac{1}{P_E}\right)^{\beta}\left(\frac{1}{P_q}\right)^{1-\beta}\left(\frac{1-\beta}{\beta}\right)^{1-\beta} \tag{8}$$

The introduction of the tradable white certificate system do not affect consumer's behavior, hence the demand functions do not changed (equations 1 to 8)

B. Energy supplier's behavior

We assume that a white certificate system with targets expressed as a percentage of energy is to be implemented. Then, energy suppliers have to save a given quantity of energy, in quantity hE proportional to their sales E. If they miss their target, they buy white certificates from energy efficiency goods firm that has complied with this obligation. We assume that the firm gets one certificate for each unit of energy-saving goods produced. A new equation is introduced since an energy

[1] A very detailed and comprehensive survey has been conducted by Reference [20]

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efficiency constraint is imposed by public authorities on energy suppliers. For given r, w, P_E and P_{TWC}, the suppliers profit-maximization behavior is the following:

$$\max_{(K_E, L_E)} \Pi_E = P_E b\, K_E^{\gamma}\, L_E^{1-\gamma} - rK_E - wL_E - P_{TWC}hE \tag{9}$$

Energy production function is defined as follows:

$$E = b\, K_E^{\gamma}\, L_E^{1-\gamma} \tag{10}$$

First-order conditions are the following:

$$(P_E - P_{TWC}h)b\gamma K_E^{\gamma-1} L_E^{1-\gamma} = r \tag{11}$$

$$(P_E - P_{TWC}h)b(1-\gamma)K_E^{\gamma} L_E^{-\gamma} = w \tag{12}$$

$$K_E = \left(\frac{\gamma}{1-\gamma}\right)\left(\frac{w}{r}\right) L_E \tag{13}$$

or:

$$L_E = \left(\frac{1-\gamma}{\gamma}\right)\left(\frac{r}{w}\right) K_E \tag{14}$$

Now substitute K_E from equation (13) into (10) and (11) to obtain:

$$E = b\left(\frac{\gamma}{r}\right)^{\gamma}\left(\frac{1-\gamma}{w}\right)^{-\gamma} L_E \tag{15}$$

$$(P_E - P_{TWC}h) = \frac{1}{b}\left(\frac{r}{\gamma}\right)^{\gamma}\left(\frac{\omega}{1-\gamma}\right)^{1-\gamma} \tag{16}$$

Also, substitute L_E from equation (14) into (10) to obtain the following:

$$E = b\left(\frac{\gamma}{r}\right)^{\gamma-1}\left(\frac{1-\gamma}{w}\right)^{1-\gamma} K_E \tag{17}$$

Then, based on (15) and (16) we get:

$$(P_E - P_{TWC}h)E = \frac{\omega}{1-\gamma} L_E \tag{18}$$

and based on (17) and (16) we get:

$$(P_E - P_{TWC}h)E = \frac{r}{\gamma} K_E \tag{19}$$

C. Appliance g producer's behavior

Profit maximization is modified as below

$$\max_{(K_g, L_g)} \Pi_g = P_g c\, K_g^{\eta}\, L_g^{1-\eta} - (rK_g + wL_g) + P_{TWC}g \tag{20}$$

Based on the first-order conditions we get

$$(P_g + P_{TWC}) = \frac{1}{c}\left(\frac{r}{\eta}\right)^{\eta}\left(\frac{\omega}{1-\eta}\right)^{1-\eta} \tag{21}$$

$$(P_g + P_{TWC})g = \frac{\omega}{1-\eta} L_g \tag{22}$$

$$(P_g + P_{TWC})g = \frac{r}{\eta} K_g \tag{23}$$

D. Appliance q producer's behavior

Compared to the BAU model, the suppliers' program and the supply function are not affected:

$$\max_{(K_q, L_q)} \Pi_q = P_q a\, K_q^{\mu}\, L_q^{1-\mu} - (rK_q + wL_q) \tag{24}$$

$$P_q = \frac{1}{a}\left(\frac{r}{\mu}\right)^{\mu}\left(\frac{\omega}{1-\mu}\right)^{1-\mu} \tag{25}$$

$$P_q q = \frac{1}{a}\frac{\omega}{1-\mu} L_q \tag{26}$$

$$P_q q = \frac{1}{a}\frac{r}{\mu} K_q \tag{27}$$

III. Comparison of Energy Saving and Rebound Effects in Business-as-Usual and Under White Certificates

A. Energy saving

(Appendix C1)

$$\frac{A^{BAU}}{A^{TWC}} = \frac{\left[\frac{\left(\frac{P_E}{P_q}\right)^{1-\beta}}{\left(\frac{P_E}{P_g}\right)^{1-\alpha}}\right]^{\frac{\rho}{1+\rho}}}{\left[\frac{\left(\frac{P_E+P_{TWC}h}{P_q}\right)^{1-\beta}}{\left(\frac{P_E+P_{TWC}h}{P_g-P_{TWC}}\right)^{1-\alpha}}\right]^{\frac{\rho}{1+\rho}}} \tag{28}$$

$$\left[\frac{A^{BAU}}{A^{TWC}}\right]^{\frac{1+\rho}{\rho}} = \left(\frac{P_E+P_{TWC}h}{P_E}\right)^{\beta-\alpha}\left(\frac{P_g}{P_g-P_{TWC}}\right)^{1-\alpha} = \frac{\frac{P_{Q_{TWC}}}{P_{Q_{BAU}}}}{\frac{P_{G_{TWC}}}{P_{G_{BAU}}}} \tag{29}$$

Regime A: if $\beta \geq \alpha$, then $\left(\frac{P_E+P_{TWC}h}{P_E}\right)^{\beta-\alpha} \geq 1$ and $\left(\frac{P_g}{P_g-P_{TWC}}\right)^{1-\alpha} \geq 1$

We have

$$\frac{P_{Q_{TWC}}}{P_{Q_{BAU}}} > \frac{P_{G_{TWC}}}{P_{G_{BAU}}} \tag{30}$$

This is equivalent to

$$\frac{P_{Q_{TWC}}}{P_{Q_{BAU}}} - 1 > \frac{P_{G_{TWC}}}{P_{G_{BAU}}} - 1 \tag{31}$$

Hence,

$$\triangle P_Q > \triangle P_G \tag{32}$$

and

$$A^{BAU} \geq A^{TWC} \tag{33}$$

Regime B: if $\beta < \alpha$ and $\left(\frac{P_g-P_{TWC}}{P_g}\right)^{1-\alpha} \leq \left(\frac{P_E+P_{TWC}h}{P_E}\right)^{\beta-\alpha} \leq 1$; then: $1 \leq \left(\frac{P_E+P_{TWC}h}{P_E}\right)^{\beta-\alpha}\left(\frac{P_g}{P_g-P_{TWC}}\right)^{1-\alpha} \leq \left(\frac{P_g}{P_g-P_{TWC}}\right)^{1-\alpha}$

so, we have

$$\triangle P_Q > \triangle P_G \tag{34}$$

and

$$A^{BAU} \geq A^{TWC} \tag{35}$$

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Vol.14 pp.21-26

Regime C: if $\beta < \alpha$ and $0 \leq \left(\frac{P_E + P_{TWC}h}{P_E}\right)^{\beta-\alpha} \leq \left(\frac{P_g - P_{TWC}}{P_g}\right)^{1-\alpha}$; then: $0 \leq \left(\frac{P_E + P_{TWC}h}{P_E}\right)^{\beta-\alpha} \left(\frac{P_g}{P_g - P_{TWC}}\right)^{1-\alpha} \leq 1$

so, we have

$$\triangle P_Q < \triangle P_G \tag{36}$$

and

$$A^{BAU} < A^{TWC} \tag{37}$$

Under regimes A and B : We have $\triangle P_Q > \triangle P_G$ and $A^{BAU} \geq A^{TWC}$, then we obtain the following(Appendix C2):

$$(\nu_{E_g}^{e_g})^{BAU} \geq (\nu_{E_g}^{e_g})^{TWC} \tag{38}$$

Under the BAU model and the white certificates scheme, an improvement in energy efficiency of the appliance g leads to reducing energy consumption E_g. In addition, energy savings obtained with white certificates are more important.
For example,

$$(\nu_{E_g}^{e_g})^{BAU} = -0.17 \geq (\nu_{E_g}^{e_g})^{TWC} = -0.30$$

An improvement in energy efficiency should lead to 17% reduction in energy consumption under the BAU model and 30% under white certificates, though this instrument generates more energy saving.

Under regime C : We have $\triangle P_Q < \triangle P_G$ and $A^{BAU} < A^{TWC}$, then we obtain the following:

$$(\nu_{E_g}^{e_g})^{BAU} < (\nu_{E_g}^{e_g})^{TWC} \tag{39}$$

In this case, energy savings generated with white certificates are less than BAU. Therefore, this instrument has no positive effect.

B. The direct rebound effect

1) Business-as-usual: The direct rebound effect is measured as efficiency elasticity of the demand for an energy service G as follows :

$$(\nu_G^{e_g})^{BAU} = \left(\frac{1}{1+\rho}\right)\left(1 + \frac{A^{BAU}\beta\rho}{\alpha + \beta A^{BAU}}\right) \tag{40}$$

Also, we have the following:

$$(\nu_G^{e_g})^{BAU} = (\nu_{E_g}^{e_g})^{BAU} + 1 \tag{41}$$

2) Under white certificates: The direct rebound effect is given by:

$$(\nu_G^{e_g})^{TWC} = \left(\frac{1}{1+\rho}\right)\left(1 + \frac{A^{TWC}\beta\rho}{\alpha + \beta A^{TWC}}\right) \tag{42}$$

Also, we have the following:

$$(\nu_G^{e_g})^{TWC} = (\nu_{E_g}^{e_g})^{TWC} + 1 \tag{43}$$

3) Comparison : ***Under regimes A and B :***(Appendix C3) we have the following

$$(\nu_G^{e_g})^{BAU} > (\nu_G^{e_g})^{TWC} \tag{44}$$

and

$$(\nu_{D_G}^{e_g})^{BAU} < (\nu_{D_G}^{e_g})^{TWC} \tag{45}$$

In each case (BAU and TWC), an improvement in energy efficiency of appliance g has an impact on increasing energy service consumption G. The direct rebound effect is generated because some or all of the expected reductions in energy consumption E_g, as a result energy-efficiency improvements are offset by an increasing demand for energy services G.
Energy efficiency improvements reduce the cost of energy service G and leads to an amount of money being saved ($D_G \searrow$). Then, consumers have an additional income which they may choose to spend on the same energy service G. This behavior may increase energy consumption E_g.
A basic finding is that under the white certificate system, the cost of energy service D_G decreases less than under the BAU. This means that a consumer has less to spend on the energy service G. Therefore, the white certificate instrument has an impact on reducing the rebound effect.

Under regime C : we have $\triangle P_Q > \triangle P_G$, then we obtain the following:

$$(\nu_G^{e_g})^{BAU} < (\nu_G^{e_g})^{TWC} \tag{46}$$

and

$$(\nu_{D_G}^{e_g})^{BAU} < (\nu_{D_G}^{e_g})^{TWC} \tag{47}$$

Since consumers may pay more to increase energy service G, the rebound effect increases under white certificates.

C. The indirect rebound effect

1) Business-as-usual: In this case, the indirect rebound effect is measured by efficiency elasticity of the demand for energy service Q

$$(\nu_Q^{e_g})^{BAU} = \left(\frac{\rho}{1+\rho}\right)\left(\frac{\beta A^{BAU}}{\alpha + \beta A^{BAU}}\right) = (\nu_{D_Q}^{e_g})^{BAU} \tag{48}$$

2) Under white certificates: The indirect rebound effect is given by:

$$(\nu_Q^{e_g})^{TWC} = \left(\frac{\rho}{1+\rho}\right)\left(\frac{\beta A^{TWC}}{\alpha + \beta A^{TWC}}\right) = (\nu_{D_Q}^{e_g})^{TWC} \tag{49}$$

3) Comparison : ***Under regimes A and B :***(Appendix C4) we have the following

$$(\nu_Q^{e_g})^{BAU} > (\nu_Q^{e_g})^{TWC} \tag{50}$$

and

$$(\nu_{D_Q}^{e_g})^{BAU} > (\nu_{D_Q}^{e_g})^{TWC} \tag{51}$$

In each case (BAU and TWC), an improvement in energy efficiency of appliance g generates an indirect rebound effect resulting from increasing income spent on energy service consumption Q.

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Under white certificates, the consumer has to spend less to increase energy service Q. As consequence, the indirect rebound effect decreases more.

Under regime C :
The white certificate instrument has an impact on increasing the indirect rebound effect as a result of an increase in the income to spend on energy service Q.

D. Discussion of the results

TABLE I
IMPACTS OF ENERGY EFFICIENCY IMPROVEMENTS AND A COMPARISON BETWEEN BAU AND TWC RESULTS

$\triangle P_G < \triangle P_Q$	**Impacts of energy efficiency improvements**		**Comparison**
	BAU	**TWC**	
E	$-$	$--$	$(-)$ decrease in energy demands so (+) increase in energy savings
g	$+$	$++$	$(+)$ increase in energy-saving good demands
P_G	$--$	$-$	$(+)$ increase in price of energy service price G
D_G	$--$	$-$	$(+)$ increase in cost of energy service G
G	$++$	+	$(-)$ decrease in demands of energy service G
D_Q	$++$	$+$	$(-)$ decrease in cost of energy service Q
Q	$++$	$+$	$(-)$ decrease in demands of energy service Q
RE_{direct}	$++$	$+$	$(-)$ decrease in direct rebound effect
$RE_{indirect}$	$++$	$+$	$(-)$ decrease in indirect rebound effect
RE_{Total}	$++$	$+$	$(-)$ decrease in total rebound effect

In Table I, we find that the tradable white certificates scheme presents additional advantage in terms of reducing energy consumption when variation in energy service price Q exceeds the variation in energy service price G (i.e $\triangle P_Q > \triangle P_G$).
In this case, energy efficiency improvement of appliance g generates more energy savings under the white certificate scheme than the BAU scheme. Energy saving is possible through: a decrease in the price of g and an increase in the price of E:

- Energy price increases as a result of energy supplier reaction. The agent covers the costs of the applied policy (TWC) through increasing energy price. This has an impact on reducing household energy demand.
- The price of energy-saving good goes down under white certificates since they are subsidized. This drop leads to an increase in efficient appliance demand, and hence reduces energy consumption.

The white certificates instrument allows for generating other benefits like its ability to reduce both direct and indirect rebound effects in regimes A and B. This may be explained by two factors:

- Note that energy service cost D_G should decrease following energy efficiency improvement. A drop in D_G is less under TWC than under BAU. This would further reduce money saving for consumers to spend on energy service G. This latter may increase demand for energy service G. This has an impact on restricting direct rebound effects.
- Note that energy service cost D_Q should increase following energy efficiency improvement. A rise in D_Q is less under TWC than under BAU. Consumers have to spend less in Q which has an impact on reducing indirect rebound effect.

IV. CONCLUSION

In this paper, we have compared the white certificates scheme as an innovative policy instrument for energy efficiency improvement to the BAU scheme. The tradable white certificates scheme can have an additional advantage in terms of energy savings and rebound effects reduction.
A basic finding is that under certain conditions, the white certificate system may be interesting to generate more energy savings because of an increase in energy price when suppliers take into account costs of certificates in their decisions, although under this instrument reduction of energy consumption and rebound effects depends on the magnitude of the variation in energy service prices.
Indeed, following energy efficiency improvements through energy-saving goods, energy service price decreases. If such a decrease is less under TWC than under BAU, an increase in the energy service demand for energy-saving goods is also less. This leads to reduce direct rebound effects.
Furthermore, energy efficiency improvement, introduced through the use of energy-saving goods, leads to an increase in the expenditure on other energy services. If such an increase is less under TWC than under BAU, an increase in the energy service demand for other energy goods is also less. This leads to reduce indirect rebound effects.

APPENDIX C

Appendix C1

Recall the following energy service prices:

$P_{G_{BAU}} = \left(\frac{P_E}{\alpha}\right)^{\alpha} \left(\frac{P_g}{1-\alpha}\right)^{1-\alpha}$	$P_{Q_{BAU}} = \left(\frac{P_E}{\beta}\right)^{\beta} \left(\frac{P_q}{1-\beta}\right)^{1-\beta}$
$P_{G_{TWC}} = \left(\frac{P_E+P_{TWC}h}{\alpha}\right)^{\alpha} \left(\frac{P_g-P_{TWC}}{1-\alpha}\right)^{1-\alpha}$	$P_{Q_{TWC}} = \left(\frac{P_E+P_{TWC}h}{\beta}\right)^{\beta} \left(\frac{P_q}{1-\beta}\right)^{1-\beta}$
$\frac{P_{G_{TWC}}}{P_{G_{BAU}}} = \left(\frac{P_E+P_{TWC}h}{P_E}\right)^{\alpha} \left(\frac{P_g-P_{TWC}}{P_g}\right)^{1-\alpha}$	$\frac{P_{Q_{TWC}}}{P_{Q_{BAU}}} = \left(\frac{P_E+P_{TWC}h}{P_E}\right)^{\beta}$

Then, the following relationship is derived:

$$\begin{aligned} \frac{\frac{P_{Q_{TWC}}}{P_{Q_{BAU}}}}{\frac{P_{G_{TWC}}}{P_{G_{BAU}}}} &= \frac{\left(\frac{P_E+P_{TWC}h}{P_E}\right)^{\beta}}{\left(\frac{P_E+P_{TWC}h}{P_E}\right)^{\alpha} \left(\frac{P_g-P_{TWC}}{P_g}\right)^{1-\alpha}} \\ &= \left(\frac{P_E+P_{TWC}h}{P_E}\right)^{\beta-\alpha} \left(\frac{P_g}{P_g-P_{TWC}}\right)^{1-\alpha} \\ &= \left[\frac{A^{BAU}}{A^{TWC}}\right]^{\frac{1+\rho}{\rho}} \end{aligned} \quad (52)$$

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Appendix C2

Under regimes A and B, we have

$$A^{BAU} > A^{TWC}$$

$$\iff \alpha + \beta A^{BAU} > \alpha + \beta A^{TWC}$$

$$\iff \frac{\alpha}{\alpha + \beta A^{BAU}} < \frac{\alpha}{\alpha + \beta A^{TWC}}$$

$$\iff -\frac{\rho}{1+\rho}\frac{\alpha}{\alpha + \beta A^{BAU}} < -\frac{\rho}{1+\rho}\frac{\alpha}{\alpha + \beta A^{TWC}}$$

$$\iff (\nu_{E_g}^{e_g})^{BAU} \geq (\nu_{E_g}^{e_g})^{TWC} \tag{53}$$

Appendix C3

Under regimes A and B, we have the following:

$$(\nu_{E_g}^{e_g})^{BAU} \geq (\nu_{E_g}^{e_g})^{TWC}$$

Or, using the following relationships:

$$(\nu_{E_g}^{e_g})^{BAU} = (\nu_{G}^{e_g})^{BAU} - 1$$

$$(\nu_{E_g}^{e_g})^{TWC} = (\nu_{G}^{e_g})^{TWC} - 1$$

We obtain:

$$(\nu_{G}^{e_g})^{BAU} - 1 > (\nu_{G}^{e_g})^{TWC} - 1$$

This leads to:

$$(\nu_{G}^{e_g})^{BAU} > (\nu_{G}^{e_g})^{TWC}$$

Appendix C4

Recall that we have these elasticities:

$$(\nu_{G}^{e_g})^{BAU} = \left(\frac{\rho}{1+\rho}\right)\left(\frac{\beta A^{BAU}}{\alpha + \beta A^{BAU}}\right)$$

$$(\nu_{G}^{e_g})^{TWC} = \left(\frac{\rho}{1+\rho}\right)\left(\frac{\beta A^{TWC}}{\alpha + \beta A^{TWC}}\right)$$

Then, $(\nu_{G}^{e_g})^{BAU} - (\nu_{G}^{e_g})^{TWC} =$

$$\frac{\rho}{1+\rho}\left[\frac{\beta A^{BAU}(\alpha + \beta A^{TWC}) - \beta A^{TWC}(\alpha + \beta A^{BAU})}{(\alpha + \beta A^{BAU})(\alpha + \beta A^{TWC})}\right]$$

$$= \frac{\rho}{1+\rho}\left[\frac{\alpha\beta(A^{BAU} - A^{TWC})}{(\alpha + \beta A^{BAU})(\alpha + \beta A^{TWC})}\right]$$

Under regimes A and B, we have the following $A^{BAU} > A^{TWC}$.
Hence,

$$(\nu_{G}^{e_g})^{BAU} > (\nu_{G}^{e_g})^{TWC}$$

References

[1] Crossley, D. J., 2008. *Tradeable energy efficiency certificates in Australia*. Energy Efficiency 1, 267-281.

[2] Oikonomou, V., Mundaca, L., 2008. *Tradable white certificate schemes: what can we learn from tradable green certificate*. Energy Efficiency 1, 211-232.

[3] Labanca, N., Perrels, A., 2008. *Editorial: Tradable White Certificates-a promising but tricky policy instrument*. Energy Efficiency 1, 233-236.

[4] Boot, P.A., 2009. *Energy efficiency obligations in the Netherlands A role for white certificates?* Energy research centre of the Netherlands, ECN-E-09-045.

[5] Brennan, T.J., 2010. *Optimal energy efficiency policies and regulatory demand-side management tests: How well do they match?* Energy Policy 38, 3874-3885.

[6] Transue, M., Felder, F.A., 2010. *Comparison of energy efficiency incentive programs: Rebates and white certificates*. Utilities Policy 18, 103-111.

[7] Langniss, O., Praetorius, B., 2006. *How much market do market-based instruments create? An analysis for the case of "white" certificates*. Energy Policy 34, 200-211.

[8] Mundaca, L., 2007. *Transaction costs of Tradable White Certificate schemes: The Energy Efficiency Commitment as case study*. Energy Policy 35, 4340-4354.

[9] Franois Greaume, F., Borde, C., 2011. *The French Energy Savings Certificates Scheme* ADEME-Agency for Environment and Energy Management.

[10] Quirion, P., 2006. *Distributional impacts of energy-efficiency certificates vs. taxes and standards*. FEEM working paper, 18.2006.

[11] Berkhout, P.H.G., Muskens, J.C., Velthuijsen, J.W., 2000. *Defining the rebound effect*. Energy Policy 28, 425-432.

[12] Birol, F., Keppler, J.H., 2000. *Prices, technology development and the rebound effect*. Energy Policy 28, 437-469.

[13] Greening, L.A., Greene, D.L., Difiglio, C., 2000. *Energy efficiency and consumption-the rebound effect-a survey*. Energy Policy 28, 389-401.

[14] Hass, R., Biermayr, P., 2000. *The rebound effect for space heating-empirical evidence from Austria*. Energy Policy (28) 403-410.

[15] Saunders, H.,1992. *The Khazzoom-Brookes postulate and neoclassical growth*. Energy Journal 13(4), 131-148.

[16] Saunders, H., 2000a. *A view from the macro side: rebound, backfire and Khazzoom-Brokes*. Energy Policy 28, 439-449.

[17] Saunders, H., 2000b. *Does predicted rebound depend on distinguishing between energy and energy services?* Energy Policy 28, 497-500.

[18] Binswanger, M., 2001. *Technological progress and sustainable development: what about the rebound effect?* Ecol. Econ. 36, 119-132.

[19] Giraudet,L.M., Quirion. P, 2008. *Efficiency and Distributed Impacts of White certificates compared to Taxes, Subsidies and Regulations*. Revue dconomie politique 119 (6), 885-914.

[20] Abdessalem, T., Labidi. E., 2015. *Economic analysis of the energy-efficient household appliances and the rebound effect*. Energy Efficiency, DOI 10.1007/s12053-015-9387-6. avalable on http://link.springer.com/article/10.1007/s12053-015-9387-6.

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