SHORT RUN SCENARIOS AND POLICIES WHEREBY ECONOMY-WIDE REBOUND EFFECTS MIGHT BE MITIGATED

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Abstract

During the last years, the so-called Rebound effects that stem from energy efficiency gains have been getting growing interest in the economic literature. This effect occurs when improvements in energy efficiency stimulate energy demand rather than reduce it. All previous analyses have considered efficiency gains as an exogenous costless energy augmenting technological change. In this paper using data on the Spanish economy for 2004 we extent previous research on this field by evaluating and analysing the economy-wide macroeconomic and welfare impacts of mitigating rebound effects under three scenarios, namely, a scenario at which energy productivity gains are compensated with capital productivity losses, a situation whereby it is labour the production factor that compensates energy efficiency improvements and a "policy-mix" that combines improvements in the intermediate use of energy along together with higher energy prices.

1 .INTRODUCTION

Rebound or Backfire effects (Jevons, 1865; Khazzoom 1980; Brookes 1990; Saunders, 1992, 2000a, b; Schipper, 2000) can be traced to the decrease in the effective or actual price of energy. Reductions in effective and/or actual energy prices lead to positive substitution, output/competitiveness, composition and income effects that act to offset the decreases in energy consumption that accompany pure efficiency effects. This is because energy efficiency improvements are in fact "factor-augmenting" or non-neutral technical change. Differently to the "Hicks-neutral technical change", factor augmenting technical change implies that proportional savings on energy inputs are greater than the average proportional savings on all inputs. Therefore, additionally to the expected output effects "non-neutrality" implies that there will be substitution effects between inputs.

Rebound effects are general rather than partial equilibrium in nature and their magnitude depends on the degree of price responsiveness of direct and derived energy demands throughout the economy in question. As a result, applied or computable general equilibrium (CGE) models have been increasingly employed for empirical analysis of conditions under which rebound effects are likely to occur in response to increases in energy efficiency. A small number of applied general equilibrium analyses of economy-wide rebound effects have been published in the energy economics literature (Grepperud and Rassmussen, 2004; Washida 2004, Hanley et al, 2006 and Allan et al, 2007) most of them analysing the case of the UK economy.

With respect to previous research, Allan et al (2007) carry out some sensitivity analysis of their rebound results for some key parameter values governing the general equilibrium price elasticity of demand for energy (in efficiency units), which determines the magnitude of the substitution, output/competitiveness, composition and income effects underlying rebound. Hanley et al (2009) similarly develop upon their earlier Scottish work. However, Turner (2008, 2009) expands upon both the Hanley et al (2006, 2009) and Allan et al (2007) studies by conducting a more systematic sensitivity analysis on the relative price sensitivity required to induce rebound effects in the

Scottish regional and UK national economies, focusing in particular elasticities of substitution in production and trade parameters. Turner's (2008, 2009) analysis suggests that (in line with early results reported by Saunders, 1992) elasticities of substitution in production are crucial in determining the magnitude of rebound effects and that rebound effects will occur even where key elasticities of substitution in production are set close to zero.

All previous research has been focused on the technological and trade market conditions that generate rebound effects. However, all these analyses have considered efficiency gains as an exogenous costless energy augmenting technological change. This implies that these productivity gains will be completely transferred to energy prices reducing the price of this input and favouring the erosion of the initial or potential energy savings leading to these perverse effects. Thus, the way in which this efficiency gains are simulated upward biases the possible rebound effects. In a more realistic scenario, firms should expend on abatement activities to reach the efficiency improvements targeted. These costs might be paid either by the private sector or by the public administration through out abatement subsidies. Nevertheless, due to the absence of detail information, we have approximated these costs of energy efficiency gains through out a compensation mechanism whereby productivity improvements in the use of energy cause productivity losses in the use of primary inputs, i.e. labour and capital. This simulation strategy is not so unrealistic since it is possible that to reduce the effective use of energy more capital or labour inputs should be needed in the production process. Additionally, another "compensation mechanism" to mitigate rebound effects consists in a policy-mix, namely, favouring energy efficiency gains while introducing or increasing taxes in the intermediate use of energy. Then, if energy input prices remain almost constant due to the simultaneous existence of these opposite effects, the wedge between potential and actual energy savings that explain rebound effects will be much lower.

Thus, in this paper using data on the Spanish economy for 2004,we extent on previous research on rebound effects by evaluating and analysing the macroeconomic and welfare impacts of mitigating rebound effects under these three scenarios, that is to say, a scenario at which energy productivity gains are compensated with capital productivity losses, a situation whereby it is labour the production factor that compensates energy efficiency improvements and a "policy-mix" that combines improvements in the intermediate use of energy along together with higher energy prices.

Additionally, another contribution of our analysis is to provide an unbiased measure of the economy-wide rebound effect. Related to this, previous empirical analysis on rebound effects have evaluated actual and potential energy savings, each of them, under different equilibrium conditions. Here in this paper we show that this practise leads to considerable downward-bias in economy-wide rebound effects and a upward-bias in backfire effects. On avoiding this bias, actual and potential energy savings, both should be evaluated under general equilibrium conditions.

The remainder of the paper is structured as follows. In Section 2 we present the definition of the economy-wide rebound-effect and our proposed unbiased measure. In Section 3 we discuss price and non-price policies to mitigate rebound effects. In Section 4 we present our simple short-run multi-sectoral CGE model of the Spanish economy. In Section 5 we present our simulation strategy and the results when evaluating the three policies mentioned above. We offer our conclusions in Section 6.

2. THE REBOUND EFFECT IN A GENERAL EQUILIBRIUM CONTEXT: DETERMINANTS AND APPROPRIATE MEASURES

As mentioned in the introduction, rebound effects (R) of energy efficiency policies stem from a reduction in the effective price of energy that erodes the potential energy savings. Thus, the definition of the rebound effect measure is one minus actual energy savings (AES) relative potential energy savings (PES). The former occurring once these price mechanisms are at work:

$$R = 1 - \frac{AES}{PES} \tag{1}$$

According to (1) we can find four different situations depending on the wedge between actual and potential energy savings:

-If $R=0 \Rightarrow AES=PES$, all potential energy savings are preserved: actual energy savings equal potential energy savings.

-If $R<0 \Rightarrow AES>PES$, rebound effects are negative meaning that there has been a positive multiplicative effect of energy efficiency policies, actual energy savings are positive and larger than potential energy savings, i.e. super-conservation of energy savings.

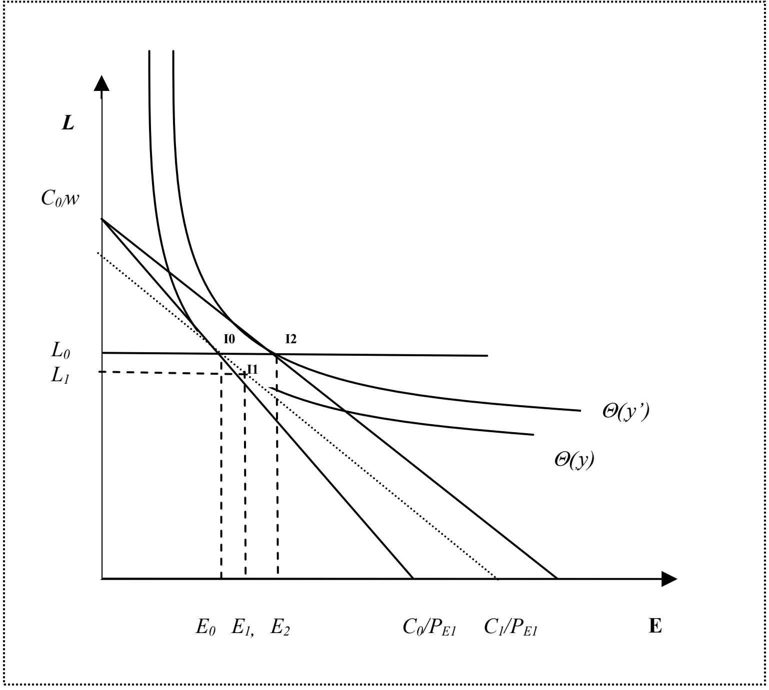
-If $1>R>0 \Rightarrow AES<PES$ positive rebound effects are at work: actual energy savings are negative and lower than potential energy savings.

-If $R>1 \Rightarrow AES<0$ this implies backfire meaning that actual energy savings are negative and larger than potential ones, all the potential energy savings has been lost.

Following Sorrell (2007) and Sorrel and Dimitropoulos (2007), in an economy-wide context these rebound effects take place through out direct and indirect "rebound effects". The former are defined as those changes in the demand of energy inputs that breaks a wedge between potential and actual energy savings that stem from a reduction in the effective price of energy occurring at an individual market level. The latter take place due to the existing inter-linkages between markets.

From standard microeconomic theory we know that, direct effects in general, and more specifically direct rebound effects from input specific efficiency gains constitute the outcome of two effects: a substitution effect (factor price effects) whereby a cheaper energy input substitutes for the use of other production inputs while maintaining the output level constant and an output or income effect that allows to produce a higher amount of output while keeping total costs constant.

Fig.1. ***Direct Rebound Effects of Energy Efficiency Policies***



The substitution and output effect that stem from an efficiency improvement in energy use are graphically illustrated in Figure 1 for two inputs-CES technology. These inputs are labour (*L*) and energy (*E*). For simplicity, we consider that the demand of labour is fixed, thus the expansion path is constant and a horizontal line. When there is a decline in the effective price of energy ($P_{E0} > P_{E1}$)due to an increase in energy efficiency, substitution effects lead to a movement along the initial isoquant (from point *I0* to point *I1*) making relatively more expensive the other input. Through this effect production of this sector becomes relatively more energy intensive. The main determinant of these substitution effects is then, the degree of curvature of the factor price frontier that is the inverse of the Hicks/direct elasticity of substitution (1932).Therefore, the lower the curvature, the higher the degree of technological flexibility and thus, the substitution effect. The direct output effects, however, are essentially scale effects that cause an outwards movement of the isoquant. These output effects also increase energy input use since more inputs are needed to produce more output (from point *I1* to point *I2*). Therefore, at a partial equilibrium context, direct rebound effects depend on the sectors' energy input demand price elasticities. The more elastic (inelastic), the larger (the smaller) the direct rebound impact from energy efficiency gains.

However, the CGE framework allows controlling not only for the aforementioned direct rebound effects but also for the indirect ones, all occurring simultaneously: rebound effects in each market (direct rebound effects) determine, among other things, changes in energy input demand in inter-related markets (substitution and income effects that generate indirect rebound effects) with a simultaneous feedback between both. Therefore, differently to the partial equilibrium models, economy-wide Rebound effects rather depend on sectors' price elasticity of demand for energy than on the general equilibrium one (Allan et al, 2006; Turner, 2008).

This CGE framework provides then a more consistent are realistic rebound measure since all the market connections are taking into account. Nevertheless, since in Walrasian equilibrium "everything" occurs simultaneously, one of the drawbacks of CGE models is the impossibility of distinguishing between pure direct rebound effects from those that are indirect. Separating these effects might have a special interest, at least for determining which industrial sectors play a mayor role in transferring the decrease in the price of energy inputs that boosts energy demand causing the erosion of overall economy-wide potential energy savings (Saunders, 2008). This might be a relevant peace of information for specific purpose, i.e. the design of complementary policies to preserving potential energy savings.

From this, we can conclude that rebound effects, direct and indirect, constitute the result of price effects, which are perverse in the case of policies that aim at reducing the use of energy in the production process. As a consequence if this price effects would not take place, all the potential energy savings will be preserve and rebound effects will not occurred.

This bring us to the conclusion that differently to what previous researchers have done economy-wide rebound measures, in a general equilibrium context, potential energy savings should not coincide with the so-called engineering energy savings also termed as policy expected energy savings. Potential energy savings should be rather defined as those energy savings that occurred when price effects are omitted, i.e. all prices are held constant and thus, no rebound is at work. These potential savings are identical to the engineering energy savings in a partial equilibrium framework. This implies that in a partial equilibrium analysis, if the policy energy efficiency goals pursue a decline of energy input use in X %, potential energy savings correspond to that X %. Thus, if an economy produces *N* commodities, under a partial equilibrium framework the expression for potential energy savings (PES^{PE}), other things held constant, are given by:

$$PES^{PE} = \frac{1}{E_i}\frac{\partial E_i}{\partial \tau_i}\bigg|_{\bar{P}_j,\bar{Q}_j} \qquad \textit{for a specific market of good } i \in N \qquad (2)$$

Where E_i, τ_i, P_j and Q_j denotes respectively energy input demand, energy efficiency gains in producing good *i* and all final market prices and quantities in the economy. The assumption of *ceteris paribus* implies that there is not any derived effect in the *N-1* remaining economy markets, nether in prices not in quantities.

This is not the case in general equilibrium models. Expression (2) above is inappropriate for this type of framework since although, prices are held constant, there is a quantity effect in interconnected markets, i.e. if there is a improve in energy efficiency we can expect that there will be a decline in the production of energy and as a consequence on the intermediate inputs used in the energy sector that, at the same time, affects other output sectors. Thus the appropriate measure of economy-wide potential energy savings (PES^{GE}) should be:

$$PES^{GE} = \frac{1}{E_i}\frac{dE_i}{\partial \tau}\bigg|_{\bar{P}_i} \neq \sum_{i=1}^{N}\frac{1}{E_i}\frac{\partial E_i}{\partial \tau}\bigg|_{\bar{P}_i,\bar{Q}_j} \qquad (3)$$

As we can assert from expression (3), notice that under a general equilibrium context is straight forward that potential energy savings do not coincide with the sum of the partial market effects. Using the sum of partial effects, as potential energy savings, downward-biases (upward-biases) economy-wide rebound (backfire) effect. We will illustrate and justify empirically the latter statement in section 5.1.

Table I. Leontief 's General Equilibrium Energy Efficiency Gains (Potential General Equilibrium Savings)

Energy Sectors	**% decline in intermediate input demand**	**% decline in total output**
2. Extraction of Anthracite, Coal, Lignite and Peat	8,688	8,566
3. Extraction of Crude, Natural Gas, Uranium and Thorium	8,554	8,528
5. Coke, Refinery and Nuclear fuels	6,116	3,553
6. Production and Distribution of Electricity	5,926	4,504
7. Production and Distribution of Gas	6,779	5,008
Economy-wide effect	***6,867***	***5,134***

To obtain an appropriate and unbiased measure of the economy-wide rebound effect actual and potential energy savings should be quantified in economy-wide terms. In doing so, we propose the input-output framework where there is complete independence between price and quantities and thus, this allows to isolating quantity from price effects making possible to get a general equilibrium measure of potential energy savings. Thus, the reported measures of the rebound effect in the present analysis have been computed using the potential energy savings depicted in Table I rather than the 5 percentage improvement exogenously evaluated in the CGE model.

3. Note about policies that might mitigate Rebound effects: Subsidies, Compulsory quotas and Taxes.

During the last few years policies that seek to promote energy efficiency pursue a limitation in the interrelationship between economic growth, energy use and environmental degradation. This is in fact the common goal of environmental policies because it is increasingly recognized that the atmospheric accumulation of greenhouse gases deteriorates progressively the environment and climate patterns. Nevertheless, differently to other green policies, energy efficiency policies present many derived effects. Some of them are positive, namely: a) energy efficiency improvements increase productivity boosting economic growth and b) energy efficiency gains favour countries' trade balance improving competitiveness levels and reducing energy imports. This explains why efficiency improvements in energy use have become one of the main concerns of the European Union Energy Policy[1]. Consequently, many European governments have enacted especial plans and policies targeted to attain this goal[2]. However, as mentioned in the introduction, energy efficiency gains can also have perverse effects eroding the initial or potential energy savings, i.e. Rebound effects.

There are different ways whereby energy efficiency gains might be reached, each of them also leading to different economy-wide impacts. Nevertheless, no matter which policy is applied, in the “real world” efficiency improvements will be always costly to society. On one hand, energy efficiency gains might be directly induced through-out non-price policies, e.g. governmental subsidies that finance the investment needed in abatement costs. Under this scenario all positive and also negative effects of the energy efficiency policy mentioned above will be present mentioned. However, if the central administration aims at maintaining its income-expenditure balance as constant as possible, some positive effects will be lower or even they might be lost. This is because the public expenditure on these subsidies might be compensated increasing tax rates on other markets with the subsequent distortions. Additionally, since firms do not internalise the costs of reducing energy use, this increases the possibility of the presence of rebound effects. On the other hand, energy efficiency gains might be rather indirectly induced charging the so-called eco-taxes or increasing energy taxes or through out “compulsory energy quotas”. In these cases, firms will have to finance on their own abatement costs, though these costs will be ultimately transferred to consumers. This restricts substitution and output effects that generate rebound.

When comparing both types of policies, tax or regulatory policies are usually not very popular among policy makers since they generate numerous barriers to the innovation and diffusion of low carbon technologies and they might have adverse impacts on income distribution and competitiveness. Additionally, these policies might be less time-effective than the implementation of subsidies because the time expend on the process of capital caption.

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[1] See “Commission Green Paper: A European Strategy for Sustainable, Competitive and Secure Energy”. March, 2006.

[2] In the case of Spain through the “Plan de Acción 2005-2007” derived from Directive E4-2004-2012.

The problem is how to generate energy efficiency gains while preserving potential energy savings. The possibility of "hybrid" policies, i.e. combining subsidies with eco-taxes or energy taxes have been already mentioned in the literature (Greening et al, 2000 and Sorrell, 2007) in order to mitigate the possible rebounds effects. Additionally "double-dividend" scenario is also possible, though it has not been jet mentioned neither by rebound economists nor by policy markets. Under a "double-dividend" scenario, energy efficiency gains will be equally financed by the government to all industries using the amount "recycled" by eco-taxes or energy taxes. This will allow the diffusion of new technologies to other sectors while limiting the lost of potential energy savings and thus, rebound effects. Additionally, since subsidies are financed through out the income generated in the energy market itself, this policy is expected to have slight distorting effects in other markets. All these arguments might position "double-dividend" energy efficiency gains policies at the top using as criteria positive economy-wide welfare effects.

Evaluating these policies is out of the scope of this analysis. However, this study offers some insides about a different scenario not analyse jet in the existing literature under which rebound effects are costly. Furthermore, when evaluating the scenario of the "policy-mix", i.e. higher energy taxes together with costless energy efficiency improvements, we answer to the question to which level energy taxes should be increased to mitigate rebound and the derived welfare costs for the case of the Spanish economy. The way in which these scenarios are simulated it will be described more extensively in section (5) below.

4. A Simple short-run multi-sectoral Empirical General equilibrium model of the Spanish economy 2004

In order to evaluate the possible rebound effects of energy efficiency policies in the context of the Spanish economy, we use a multi-sectoral static applied general equilibrium model for an open and small economy such as the Spanish one. Our model is calibrated on a Social Accounting Matrix for the base year of 2004 constructed by the authors .On calibrating the model, we have included initial tax rates following the methodology proposed by Sancho, F (2009). In this economy there are four different agents: Firms (F), Households (H), Government, (G) and foreign sector (FS) whose behaviour is described in the following subsections.

4.1. Firms

Firms are assumed to participate in the economy throughout two different activities: producing goods and services and making income distribution operations, i.e. firms make transactions with the rest of the agents in terms of property income, social contributions and transfers. Related to production, a representative firm of each industry minimizes costs subject to zero profits. Therefore, we assume perfect competition and thus, constant returns to scale. We follow the Armington (1969) assumption whereby imported products are imperfect substitutes for domestic production. To get sectors' final domestic output, production inputs (capital, labour, materials and energy) are combined within a succession of nested constant elasticity of substitution (CES) functions (see Figures 1-2 in Annex). 16 sectors and thus, commodities are identified, 5 of which are energy supply sectors (see sector listing in Appendix). Two relevant production blocks are distinguished in the economy: the energy block (sectors 2-3 and 5-7 in Appendix) and the non-energy block (sectors 1, 4 and 8-16). Both blocks make use of a multi-level and sectors' homogenous technology.

4.1.1. Firms' Production Activity

Domestic and foreign production

On producing final gross output, as mentioned above, we assume that the degree of substitution between domestic and imported goods is partial. Thus, final output in each production sector *i* is a composite between domestic (X_{D_i}) and imported production (X_{M_i}) obtained throughout a CES technology:

$$X_i = \left[(a_{D_i} X_{D_i})^{\rho_i} + (a_{M_i} X_{M_i})^{\rho_i} \right]^{1/\rho_i} \qquad \forall i = 1, \ldots\ldots N \quad N=16 \tag{5}$$

Where, a_{D_i}, a_{M_i} and ρ_i are respectively the domestic and foreign input technical coefficients and the exogenous parameter that determines the elasticity of substitution between both. In our model we consider different Armington elasticities for the energy and non-energy block, though, homogenous within blocks. Estimates of the short-run Armington elasticities of substitution are in fact, average values overall European members taken from previous empirical analysis (Hertel, 1997, Nèmeth et al, 2008). According to the latter analysis, short-run elasticities for energy inputs are around 1.68 while for non-energy sectors are on average 0.9 thus, closed to a Cobb-Douglas technology. Additionally, the assumption of a small economy makes world prices to be exogenously determined.

Domestic Production: KLEM specification

Production of the domestic good X_{Di} in each sector *i* is determined along with a KLEM (Capital, Labour, Energy and Materials) nested production function. The Energy and Materials composite inputs are introduced along with capital (K) and Labour to the nested KLEM production function in the following way corresponding to configuration 6 outlined below: in order to obtain the non-energy value-added (VA) input, conventional Capital (K) and Labour (L) are combined first. The Hicks elasticity of substitution parameter considered between K and L, $1/(1-\rho_{KL}) = \sigma_{KL}$, is 1.26 and it has been also taken from previous empirical studies (Hertel, 1997) and equal for all sectors. Then, at the second level, this combination is used as an input together with energy materials composite (E) to give us a value-added/energy composite, VAE, which then combines at the third level with non energy materials composite (M) to give us domestic output, X_{Di}:

$$
\begin{aligned}
X_{Di} &= \left(\alpha (A_M M_i)^{\rho^i_{M,VAE}} + (1-\alpha) VAE)_i^{\rho^i_{M,VAE}} \right)^{1/\rho^i_{M,VAE}} \\
VAE_i &= \left(\beta (\tau E_i)^{\rho^i_{VA,E}} + (1-\beta) VA_i^{\rho^i_{VA,E}} \right)^{1/\rho^i_{VA,E}} \qquad (6) \\
VA_i &= \left(\delta (A_K K_i)^{\rho^i_{K,L}} + (1-\delta) (A_L L_i)^{\rho^i_{K,L}} \right)^{1/\rho^i_{K,L}}
\end{aligned}
$$

The parameter related to the elasticity of substitution between the value added composite and energy, $\sigma_{VA,E}$ takes the value of 0.5 with the exceptions of sectors 11 and 12 in the Annex that present a value of 0.96 and 0.8 respectively. The elasticity of substitution between the value added-energy composite and materials, $\sigma_{M,VA-E}$ equals 0.5 for all sectors. These parameters are based upon the econometric estimates of Kemfert and Welsch (2000). The Factor efficiency is input specific and represented by A_j for each capital, labour and materials, which remains constant in the simulations presented in this paper. In this paper we simulate energy efficiency gains, which take place in the energy composite and are reflected in the parameter τ in (6). This implies that energy efficiency gains are exogenously simulated using a factor augmenting or "non-neutral" technical change equal in all sectors. The KLEM structure considered in (6) stems from the conclusions obtained through out the empirical analysis for the Spanish case made by Vega-Cevera and Median (2000).

For simplicity, the non-energy Materials input composite to each sector *i* is a Leontief combination of the 11 non-energy inputs identified in Appendix. For the same reasons, the composite Energy input is a combination of five energy sources, specifically the outputs of the five local energy supply sectors. Future research will relax the latter assumption introducing imperfect substitution between primary and secondary energy inputs (Böhringer, Ferris and Rutherford, 1997) and between renewable a non-renewable.

This is a short-run model where the supply of capital is fixed, but, while population and the participation rate are fixed, we have unemployment in our in initial equilibrium (given by the Spanish SAM data for 2004). This introduces some flexibility in labour supply. We assume a wage curve (see Blanchflower and Oswald, e.g. 1990, 1995) that reflects the relationship between real-wages and unemployment, so that unemployment and labour demand are endogenous while the total supply of labour is held fixed. The specification of the wage curve is given by:

$$w / cpi = u^{\beta} \tag{7}$$

where:

$$w / cpi = real \quad wages$$
$$u = unemployment\, rate$$
$$\beta = relation \qquad real\, wage - unemployment$$

The value of β equals -0.13 and is an average estimated elasticity for the case of Spain (Sanromà y Ramos, 2003).

4.1.2. Firms' Income Distribution Operations

As mentioned above, firms play a role in the process of disposal income formation. However, there is not information to sophisticate the firms' behaviour that concerns to this activity and thus, its characterisation here assumed is rather a simple income-expenditure restriction:

$$(1 - t_{IT}^{F}) r\overline{K}_{F} + \sum_{a \in A} \overline{NT_{F}^{a}} = P_{I} S_{F} \tag{8}$$

where:

t_{IT}^{F} Firms' income tax rate

$r\overline{K}_{F}$ The Value of Fixed Capital Services Endowment of Firms

$\sum_{a \in A} \overline{NT_{F}^{a}}$ Firms' Income Distribution Operations among agents, $a \in A = F, H, G, FS$

$P_{I} S_{F}$ Value of Firms' Savings

4.2. Households: Calibration of a Linear Expenditure System.

Consumption, *C*, and Saving, *S*, activities of a representative household are characterised using a Cobb-Douglas utility function:

$$U(C, S) = \prod_{i=1}^{N} C^{\alpha} S^{(1-\alpha)} \tag{9}$$

Thus, consumption, C, and savings, S, of the representative utility maximizing household constitute a constant share over disposable income α . Gross consumer's income comes from labour, capital revenues and overall transfers, i.e. social transfers, other transfers, property income transfers. From the after income tax or net income (*mn*) other transfers are deducted since they are not subject to taxation.

Consumption behaviour, C, is here represented through out a linear expenditure system (LES):

$$U_c = \Pi(C_i - c_i)^{\delta_i} \qquad i = 1.....N \tag{10}$$

Donde es el consumo total del bien i-ésimo y es el consumo mínimo de subsistencia del mismo bien, el cual es independiente de las variaciones de renta y precios. El parámetro representa, sin embargo, la ponderación que el consumo no indispensable tiene sobre el nivel de utilidad del consumidor.

Where C_i refers to total quantity consumed of the *ith* commodity and c_i denotes the "subsistence" consumption. Thus, according to (10) consumption activities will contribute by the weight δ_i positively to utility levels, as far as the basic needs had been fulfilled. Solving the problem of a utility-maximizing consumer, the optimal quantity demanded for the ith commodity is characterised by:

$$C_i = \bar{c}_i + \frac{\delta_i}{P_i}\left(\alpha mn - \sum_{j=1}^{N} P_j c_j\right) \tag{11}$$

Differently to the Cobb-Douglas and CES utility functions, the most widely-used forms in CGE modelling, the LES structure allows income elasticities of demand to vary across commodities. These income elasticities for the consumption of the N commodities are based upon the empirical estimates in Theil et al. (1989) (See Table II). These estimates were adjusted to fulfil the Engel aggregation property. However, another parameter should be known in order to correctly calibrate "subsistence" quantities, c_i. This parameter is the Frisch parameter (1959) which is the expenditure elasticity of the marginal utility of expenditure:

$$\varphi = -\frac{\alpha mn}{\alpha mn - \sum_{i=1}^{N} p_i c_i} \tag{12}$$

The estimate of the Frisch parameter is based upon the analysis made by Lluch et al (1977) for the European Union and is equal to ***-2.07.***

Table II: Estimates of income Elasticities.

Sectors	***Income Elasticities***
Extraction of Anthracite, Coal, Lignite and Peat	**0.09**
Extraction of Crude, Natural Gas, Uranium and Thorium	**0**
Coke, Refinery and Nuclear fuels	**1.2**
Production and Distribution of Electricity	**1.2**
Production and Distribution of Gas	**1.2**
Primary Sector	**0.1**
Other Extraction Industries	**0.1**
Water Sector	**0.4**
Food, Beverage, Tobacco, Textile and Leather Products	**0.55**
Other Industrial Sectors & Recycling	**1.4**
Chemistry Industry, Rubber and Plastic Industry	**1.4**
Manufacturer Industry: Minerals, Furniture, Metallic Products, Equipment & Electronic Products.	**1.5**

4.3. Government

Government's behaviour consists of recycling taxes from consumption, production and income generation .These taxes together with the income generated from capital endowments and other transfers allow the public sector to buy public goods in fixed proportions, carry on investment activities and transfers operations to other agents in the economy. Thus, the government's savings are endogenous in this model.

4.4. Foreign Sector and Macroeconomic Closure Rule

Since Spain is an open economy, the trade balance, i.e. import and exports might be positive (surplus) or negative (deficit). Furthermore, macroeconomic consistency rules establish that the trade balance between our economy and foreign economies has to be translated into foreign sectors' savings (S_x) that is a component of total investment. The model macroeconomic refers then, to the balance between investment and savings. Investment is determined through economic agents' savings and is given by:

$$I = S_F + S + S_G + S_{FS} \tag{13}$$

Therefore, total investment in the economy, *I,* is the sum of overall agents' savings: firms savings S_F determined by *(8),* Household savings*, S,* Government Savings S_G*,* and Foreign sector savings, S_{FS}*.* As usually done in CGE models, a Leontief technology describes the production of investment activities, thus investment coefficients are assumed as fixed, $\overline{cIv_i}$. Its price, P_I, is a weighted average of commodities final gross prices, P_i^G :

$$P_s = \sum_{i \in N}^{N} \overline{cIv_i} P_i^G \tag{14}$$

Lastly, the capital net rental price is the numeraire considered in the applied general equilibrium model described above.

5. RESULTS

5.1. Simulation Strategy

Using the standard model described in (5) four alternative scenarios will be contemplated, all of them will considered energy efficiency gains as an exogenous energy augmenting technological progress (i.e. increasing units of output produced per unit of energy input) applied to the use of domestically supply energy, and not imported energy inputs. Thus, we introduce the energy efficiency shock by increasing the productivity of the energy composite by 5 percentage points, i.e. $\tau = 1,05$ in the domestic production structure shown in (6) for each of the 16 production sectors here considered. This scenario will be taken as a reference for the other three scenarios. Under the first two scenarios, productivity improvements in the use of energy in the production process are compensated through a decline in the capital and labour factor augmenting component in (6) (A_K, A_L). These parameters will be exogenously varied till the overall rebound effect equals zero and thus, all the potential energy savings are preserved. Under the third and last scenario, an ad valorem tax is added up to the intermediate consumption of energy that also will take different values till the frontier between positive rebound and a super-conservation scenario is reached.

5.2. Simulation Results

Before comparing the results of the different simulated scenarios presented above, in this section, firstly, we briefly discuss the size and direction of the biases of the economy-wide Rebound effect measures. As mentioned in section 2, this bias is the consequence of using potential energy savings that stem from a partial equilibrium context rather than using those corresponding to a general equilibrium one.

5.2.1. Comparing Economy-Wide Rebound Effect Measures.

Usually "rebound economists" making use of the CGE framework, compute economy-wide rebound measures as 1 plus the simulated proportionate change in total energy input used divided by the evaluated proportionate change in energy efficiency:

$$R^b = \left[1 - \frac{dE/E}{\tau - 1}\right] \times 100 \tag{15}$$

As mentioned in section 2, expression (15) is a biased measure of economy-wide rebound effects because the general equilibrium potential energy savings do not coincide with those at a partial equilibrium context, i.e. the evaluated proportionate change in energy efficiency also known as engineering energy savings. In our proposed unbiased measure, both actual and potential energy savings correspond to general equilibrium measures. Thus, differently to (15), the simulated proportionate change in total energy input or actual energy savings is relative to the general equilibrium decline in this input when prices are held constant:

$$R^u = \left[1 - \frac{dE/E}{PES^{GE}}\right] \times 100 \tag{16}$$

The denominator in (16) is what we have termed general equilibrium potential energy savings, PES^{GE}. This measure has been obtained using the well-known Leontief quantity model simulating a reduction in the input-output coefficients related to energy inputs by 5 percentage points under the assumption that final use of production is held fixed. These results of the PES^{GE} for 5 percentage improvement in energy input demand are summarised in Table 1 in section (2). According with these results, in a general equilibrium context, potential energy savings are remarkably above engineering or policy expected energy savings, i.e. the former represents almost 40 percent over the latter. This is explained by the negative multiplicative effect that the decrease in energy input use has over its connected markets. A decline in energy intermediate use leads to a reduction in its intermediate demand affecting output levels of those sectors providing inputs to the energy block. This, at the same time, pushes down even more energy input demand. Since $PES^{GE} > PES^{PE}$ the use of (15) instead of (16) downward-biases economy-wide rebound effects and upward-biases backfire effects. Therefore, under (15), if the simulated proportionate change in intermediate energy use turns to be positive (negative), the increase (decrease) in energy input demand must be larger than under (16) to find positive rebound or backfire (super-conservation effect). In other words, if we use R^u instead of R^b, technology should be more "elastic" to get rebound or backfire and less "elastic" to find no-rebound or a super-conservation scenario.

Table III: Rebound Measures of a 5 % simulated costless-exogenous increase in energy efficiency gains

Rebound Measures and Distance	***Benchmark Elasticity Values***	**Case1:** $\sigma^i_{VA,E}$ **increased by 10%**	**Case 2:** $\sigma^i_{VA,E}$ **increased by 15%**	**Case 3:** $\sigma^i_{VA,E}$ **increased by 20%**
R^b	82.652	91.014	95.213	147.910
R^u	87.330	93.416	96.472	165.886
$(R^u - R^b)/R^u$	0.053	0.0257	0.0130	-0.123

Economy-wide Rebound effect measures for the KLEM specification in (6) when the elasticitity of substitution between value-added and energy, $\sigma_{VA,E}$, varies are shown in Table III above (See Saunders and Sorrell, 2007 for the relevance of this elasticity on the presence and size of rebound effects). Also this table shows the distance between $R^b - R^u$ relative to our unbiased proposed measure. Note that the higher the elasticity of substitution, the higher the rebound. As was pointed out by previous empirical research (Allan et al, 2007 and Turner, 2008) the degree of concavity of the isoquants is positively related to the presence and size of the rebound effects of energy efficiency policies. Observe also that no matter which are the values of elasticity of substitution, the evaluation of a 5 percentage efficiency increase in intermediate energy use always leads to positive economy-wide rebound or even backfire, i.e. $0 < R^u < 100; R^u > 100$. Recent theoretical work developed by Saunders (2008), though using a more simplify framework, might help to partially justify this finding. Saunders (2008) was first to analyse the propensity of each of the more commonly used production/cost functions to unintentionally condition the presence of “rebound effects”. With respect to production functions, this author examined and compared four functional forms to exhibit the four possible rebound effects already described in section (2). Namely: the Leontief, the Cobb-Douglas, the the Hogan-Manne-Richels (1977, 1990), and the Generalized Leontief function. According to this analysis, the Hogan-Manne-Richels (1977, 1990), which is a special case of Nested CES production functions, might not be considered as “rebound flexible” because its impossibility to generate a “super-conservation” scenario. Additionally, Saunders (2008) pointed out that the same conclusion applied to any kind of Nested CES specifications. Thus, independently from the parameter values of the elasticity of substitution, we find a positive economy rebound effect in the Spanish economy basically because the functional form we have used to describe technology.

5.2.2. Costly energy efficiency gains and policy-mix.

The results of the four simulations described in section (5.1) are depicted in Table IV-VII. Table IV shows the results of some macroeconomic and welfare measures of an exogenous one-off costless 5 percentage productivity increase in the intermediate use of energy. As can be asserted from this table, the impact these energy efficiency gains decreases the effective price of this input generating a decline in overall price levels, i.e. e Laspeyres Index of Energy prices and the Consumer price index (CPI) decrease respectively by 3 and by 1,1 percentage points, because energy costs constitute a composite in commodities’ final prices. Due to the substitution and output effects already explained in section (2), this decline in energy price boosts even more the intermediate energy use causing the erosion of potential energy savings and thus, a short-term economy-wide rebound effect that accounts for 87,33 percentage points. Among previous research on this field that have used the same methodology (Semboja, 1994; Vikstrom, 2004; Washida, 2004; Grepperud and Ramussen, 2004; Hanley et al. 2006 and Allan et al. 2007) our model is much closer to that made for the case of the UK economy (Allan et al. 2007). To this extent, these authors have also assumed that value added combines with the energy inputs. They found a 37 percentage economy wide rebound effect, a figure far below our result. Although it is difficult to compare these studies due to the different model structure, parameter values, base period data and the structure of each economy itself, the reason why we find higher rebound might be that differently to Allan et al. (2007), there is imperfect substitution between value added an energy in our model. Therefore, if the energy input coefficient is variable instead of fixed, we can expect that substitution effects will be much higher and then, the economy-wide rebound effect. However, in spite of the presence of this perverse effect, output effects that stem from energy efficiency gains raise remarkably real GDP and welfare levels. Additionally, there is another positive effect from energy efficiency improvement over the labour market, namely, the decline in unemployment rate that follows real wage falls.

Table IV. Simulation 1:
One-off Costless 5 % Energy efficiency improvements

Macroeconomic & Welfare Measures	$\tau = 1{,}05$ $A_K = A_L = T_E = 0{,}00$
% Δunemployment	*-9,258*
% Δ Real GDP	*12,122*
Equivalent Variation at basic prices (Millions of Euros)	*-266,714*
%Δ Laspeyres Index of Energy Prices	*-3,023*
Rebound Effect	*87,330*
% ΔReal Wage	*0,167*
% ΔCPI	*-1,107*

Table V and VI show the results of a very different scenario whereby energy efficiency gains, though still exogenous, are costly. In Table V, these costs stem from capital productivity losses. Thus, in this simulation we assume that productivity improvements in energy inputs make less productive fixed capital. Since the decline in the effective price of energy is compensated through out an increase in the effective price of capital (an input that is also used in the production of energy) economy-wide rebound effects are much lower getting zero when capital productivity losses accounts for almost 8 percentage points. Additionally, when rebound effects are mitigated along with this mechanism, output effects go in the opposite direction to that under simulation 1 due to the overall increase in prices. Thus, production and consumption activities decline and consequently, real GDP. Similar conclusion can be drawn from Simulation 3 (Table VI), in this case productivity losses that accompany energy efficiency improvements occur in the labour factor. This explains the higher sensitivity of unemployment rates under this scenario whereby no rebound takes place when labour productivity losses are closer to 7 percentage points. Although in order to get no rebound "productivity costs" and the derived decline in prices are below scenario 2, the negative impact over real GDP is much higher explained by the higher weight that labour has over value added formation.

Table V. Simulation 2:
Costly 5 % Energy efficiency improvements compensated with Capital efficiency losses

Macroeconomic & Welfare Measures	$\tau = 1,05$ $A_K = 0,925$	$\tau = 1,05$ $A_K = 0,95$	$\tau = 1,05$ $A_K = 0,975$	$\tau = 1,05$ $A_K = 0,922$
% Δunemployment	*-39,199*	*-22,464*	*-6,011*	*-41,386*
% Δ Real GDP	*-5,652*	*-3,345*	*-1,072*	*-5,918*
Equivalent Variation at basic prices (Millions of Euros)	*1347,042*	*805,281*	*267,371*	*1417,32*
%Δ Laspeyres Index of Energy Prices	*4,068*	*1,578*	*-0,781*	*4,399*
Rebound Effect	*3,648*	*31,744*	*59,637*	*0,004*
% ΔReal Wage	*-0,625*	*-0,362*	*-0,098*	*-0,659*
% ΔCPI	*6,085*	*3,508*	*3,508*	*6,339*

Table VI. Simulation 3:
Costly 5 % Energy efficiency improvements compensated with Labour efficiency losses

Macroeconomic & Welfare Measures	$\tau = 1,05$ $A_L = 0,925$	$\tau = 1,05$ $A_L = 0,95$	$\tau = 1,05$ $A_L = 0,975$	$\tau = 1,05$ $A_L = 0,931$
% Δunemployment	*-64,167*	*-39,334*	*-14,546*	*-57,534*
% Δ Real GDP	*-7,456*	*-4,581*	*-1,690*	*-6,699*
Equivalent Variation at basic prices (Millions of Euros)	*1366,192*	*820,740*	*276,330*	*1220,472*
%Δ Laspeyres Index of Energy Prices	*3,028*	*0,916*	*-1,098*	*2,454*
Rebound Effect	*0,498*	*23,388*	*55,338*	*0,008*
% ΔReal Wage	*-1,006*	*-0,627*	*-0,236*	*-0,906*
% ΔCPI	*6,010*	*3,523*	*1,1527*	*5,334*

Lastly Table VII presents the results when energy efficiency gains are simultaneously exogenously introduced with an ad-valorem tax in the intermediate use of energy. According to our results, 5,725 energy tax percentage rate is needed to mitigate rebound with modest costs over society and a slightly impact overall macroeconomic measures. Comparing these findings to that obtained under scenario 2 and 3, the macroeconomic and welfare effect over initial levels is much lower indicating the high effectiveness of this "policy-mix" scenario to reduce rebound effects. This is not a surprising result since the compensation mechanism, the ad-valorem tax, is including in the energy market itself and generates additional income what imply lower distortions to overall economy.

Table VII. Simulation 4:
Costly 5 % Energy efficiency improvements combined with ad-valorem Energy Tax

Macroeconomic & Welfare Measures	$\tau = 1,05$ $T_E = 2,5\%$	$\tau = 1,05$ $T_E = 5\%$	$\tau = 1,05$ $T_E = 7,5\%$	$\tau = 1,05$ $T_E = 5,725\%$
% Δunemployment	*5,506*	*0,770*	*-3,884*	*-0,582*
% Δ Real GDP	*0,802*	*0,391*	*-0,021*	*0,271*
Equivalent Variation at basic prices (Millions of Euros)	*-131,038*	*3,234*	*136,161*	*4,191*
%Δ Laspeyres Index of Energy Prices	*0,951*	*5,012*	*9,161*	*6,206*
Rebound Effect	*48*	*10,567*	*-251,01*	*0,004*
% ΔReal Wage	*0,897*	*1*	*-0,063*	*-0,001*
% ΔCPI	*-0,547*	*1*	*0,574*	*0,172*

6. Concluding Remarks.

The key focus of the analysis using data on the Spanish economy for 2004 was to extend previous analysis on the economy-wide rebound effect considering three different scenarios whereby this perverse effect from energy efficiency gains might be mitigated. These scenarios consist in introducing a compensation mechanism that goes in the opposite direction to that of the effective price energy when energy efficiency gains occur. Under the first two scenarios, productivity improvements in the use of energy in the production process are at the expense of a decline in capital and labour productivity levels. Thus, we assume that when energy inputs become more efficiency either more capital and labour and needed. According to our results, rebound effects are mitigated when productivity levels of capital and labour fall respectively by 8 and 7 percentage points causing remarkable negative impacts over real GDP and welfare levels. Under the third and last scenario, an ad-valorem tax is added up to the intermediate consumption of energy. In this case, no rebound occurs when charging 5,725 energy tax percentage rate with a slight impact over macroeconomic and welfare levels. Among other things, this implies the high effectiveness of this policy-mix when seeking reducing or eliminating rebound effects from energy efficiency gains. This is why many analysts and policy makers have recommended the co-existence of energy efficiency improvements with higher energy taxes. Furthermore, there is another reason for this postulate: while at short term they are cost-effective tools to mitigate rebound, at long term higher energy taxes might induce technological change that will further increase energy productivity.

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Appendix: ***Sectorial breakdown for Spanish I/O 04 Data***

Aggregation ordering in symmetric table	*Classification*	*Sectors*	*NACE-93 code*
2	***Energy Sectors***	***Extraction of Anthracite, Coal, Lignite and Peat***	**10**
3		***Extraction of Crude, Natural Gas, Uranium and Thorium***	**11-12**
4		***Coke, Refinery and Nuclear fuels***	**23**
5		***Production and Distribution of Electricity***	**401**
6		***Production and Distribution of Gas***	**402-403**
1	***Non Energy Sectors***	***Primary Sector***	**01, 02, 05**
7		***Other Extraction Industries***	**13-14**
8		***Water Sector***	**41**
9		***Food, Beverage, Tobacco, Textile and Leather Products***	**151-152, 154-155, 156-159, 16-19**
10		***Other Industrial Sectors & Recycling***	**20-22,37**
11		***Chemistry Industry, Rubber and Plastic Industry***	**24-25**
12		***Manufacturer Industry: Minerals, Furniture, Metallic Products, Equipment & Electronic Products.***	**261-268, 27-36**
13		***Construction***	**45**
14		***Commercial & Transport Activities***	**50-52, 61-62, 601-603, 63.1-63.2, 63.4**
15		***Market Services***	**65-67, 70-72, 74, 80, 85, 90, 92, 93, 63.3**
16		***Non Market Servicies & Public administration***	**75, 80, 85, 90, 92**