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The use of "Bonus-Malus" schemes for promoting energy-efficient household appliances: a case study for Spain

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Subsidies to promote the purchase of energy-efficient household appliances have been extensively used in many countries. This paper deals with the case of the Spanish rebate scheme, and proposes the use of both subsidies and taxes as a more effective way of promoting efficient appliances. The authors propose a sophisticated methodology for designing optimal combinations of taxes and subsides depending on different policy goals such as budget neutrality, increasing the proportion of efficient appliances, etc.

Keywords: energy efficiency, Spain, rebates, appliances, rebound effect.

JEL Classification: C13, C20

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1. Introduction

Since the turn of the 21st century several authors have analysed the potential of energy efficiency labels for promoting energy policies (Banerjee and Salomon, 2003, Sanchez et al., 2008, Webber et al., 2000, Abadie and Galarraga, 2012, Galarraga and Abadie, 2011, Galarraga et al., 2011a and Galarraga et al. 2011b).

Markandya et al. (2009) look at rebate schemes for labelled appliances, and show that in some cases they might be cost-effective. Galarraga et al (2013) offer a review of the literature on the use of subsidies for labelled goods in the field of energy efficiency. They look at the use of labelling programmes to set up a rebate scheme in Spain: the so-called Renove programme for dishwashers. They find that when a subsidy is introduced to support the purchase of efficient appliances (i.e. those holding an A or A+, A++ label) an increase in energy bills can be expected as a consequence of the increase in the total number of appliances, which grows by 1.4-2% while the number of labelled dishwashers increases by 4.8-7.7%[1]. They also find that a welfare loss is generated as a consequence of the use of the subsidy, which is explained by the inefficiency of any subsidy scheme. Other papers have reported similar findings, e.g. Datta and Gulati (2011) estimate that an increase of 1 USD in rebates results in a 4.5% increase in the share of energy-efficient clothes washers labelled with Energy Star in the US. Revelt and Train (1998) offer estimates of the impact of both instruments for the case of refrigerators.

In line with the literature on "Feebates" (a term coined as a combination of 'fee' and 'rebate') (see Eilert et al, 2010 for a good review), Galarraga et al (2013) advocate the simultaneous use of both taxes and subsidies in what is called a Bonus-Malus scheme (or Feebate), i.e. taxing the "bads" (inefficient appliances) to subsidise the goods (labelled dishwashers). This should enable the subsidy scheme to be partially financed by taxes, thus significantly reducing the cost of the policy.

The paper presented here builds on the findings of Galarraga et al (2013) to develop a more sophisticated method for designing such a policy instrument. This new method offers a much powerful tool for optimising the combination of taxes and subsidies. The method can be used to analyse several groups of goods. In the application presented here we focus on a case with two goods (efficient and non-efficient appliances) but the theoretical description can be applied to any number of goods. When data become available for more goods a more exhaustive analysis will be possible.

In addition, by contrast with the previous paper, which only focuses on analysing one appliance (dishwashers) in one region, here we deal with three household appliances (dishwashers, refrigerators and washing machines) and six representative regions in Spain.

The paper is organised as follows: Section 2 shows some examples where the policy instruments are studied, while Section 3 is devoted to the modelling details. Section 4 presents the data for Spain and the optimisation process. Section 5 shows some results and Section 6 offers some conclusions.

[1] The authors state that although the rebate is designed to keep the total amount of appliances constant as it is only granted in exchange for an old one, many "old appliances given in exchange are already disused and recovered merely to benefit from the rebate".

2. The Bonus-Malus policy instrument

The Bonus-Malus is a well-known, extensively researched topic in the economics of risk management and insurance companies (Chiappori and Salanie, 2000, Lemaire, 1988). Fewer examples have been studied with a view to understanding the impact of using the concept to subsidise products that generate an environmental benefit (or significantly lower environmental damage) while taxing those that generate a negative impact. Some American authors refer to this topic as “Feebate schemes”. Examples have been proposed for the car market in the US (Langer, 2005; Banerjee, 2007), for fuel efficiency (Greene et al. 2005), for vehicles in France based on CO2 emissions (ASE, 2009), for food groups (Gustavsen and Rickertsen, 2013), for fair trade and regular coffee (Galarraga and Markandya, 2006) and for nitrogen oxide (NOx) in Sweden (Johnson, 2006).

Other applications include rebates for energy efficiency in buildings at state level in the US (Eilert et al, 2010). That paper concludes that feebates can “complement existing efficiency programs by providing greater support to newer, more expensive but highly efficient technologies, as well as by providing a new mechanism to tap into saving potential in hard-to-reach market segments”.

Limited work has been carried out on the case of energy-efficient appliances. Some examples are Galarraga et al (2013) for the case of Spanish dishwashers carrying the EU energy efficiency label, and Rivers and Peter (2007) for Canadian appliances labelled under the Energy star programme. We rely on some of the findings presented in the first of these papers and some new data recently released for Spain.

3. The modelling effort

3.1 The model

In order to estimate the effects in both close substitute markets we follow the adaptation in Galarraga et al (2013). Note that we are only interested in understanding the effect between these two goods and thus we do not account for the welfare impact on the rest of the goods in the economy. Nor do we consider the existence of other distorting taxes (subsidies) in the appliances market. This caveat was also highlighted in previous papers.

We define the following isoelastic demand and supply functions:

$$x_i = P_i^{\mu_{ii}} P_j^{\mu_{ij}} m^{\eta_1} \quad i \neq j \ , i = 1,\ldots,n \tag{1}$$

$$x_i = P_i^{\varepsilon_{ii}} P_j^{\varepsilon_{ij}} \quad i \neq j \ , i = 1,\ldots,n \tag{2}$$

where P_i is the price of goods, m is income, μ_{ii} is the Marshallian (Uncompensated) own price demand elasticity for product *i*, μ_{ij} is the Marshallian (Uncompensated) cross price demand elasticity, ε_{ii} is the own price supply elasticity for good *i*, ε_{ij} is the cross price supply elasticity and η_i is the income elasticity of the *i*-th product.

For the sake of simplicity we assume that supply is perfectly elastic ($\varepsilon_{ii} = \varepsilon_{ij} = \infty$), which reflects the fact that if demand increases significantly goods in most categories can easily be imported from elsewhere in Europe.

For the Dead Weight Loss (DWL) of the multiple taxes (and subsidies) we use the approximation by Stern (1987) and Tresch (1981),

$$DWL = 0.5\sum_{i=1}^{i=n}\sum_{j=1}^{j=n}\tau_i\tau_j P_i P_j S_{ij} \tag{3}$$

where S_{ij} is the Compensated change in the demand for good *i* when there is a change in the price of good *j*.

3.2 Solving the model

Taking logs and differentiating equations (1) and (2), for the *n* goods case we have the following demand functions:

$$\frac{\Delta q_1}{q_1} = \mu_{11}\frac{\Delta p_1}{p_1} + \mu_{12}\frac{\Delta p_2}{p_2} + \ldots + \mu_{1n}\frac{\Delta p_n}{p_n} + \eta_1\frac{\Delta m}{m} \tag{4}$$

$$\frac{\Delta q_2}{q_2} = \mu_{21}\frac{\Delta p_1}{p_1} + \mu_{22}\frac{\Delta p_2}{p_2} + \ldots + \mu_{2n}\frac{\Delta p_n}{p_n} + \eta_2\frac{\Delta m}{m} \tag{5}$$

$$\frac{\Delta q_n}{q_n} = \mu_{n1}\frac{\Delta p_1}{p_1} + \mu_{n2}\frac{\Delta p_2}{p_2} + \ldots + \mu_{nn}\frac{\Delta p_n}{p_n} + \eta_n\frac{\Delta m}{m} \tag{6}$$

and supply functions:

$$\frac{\Delta q_1}{q_1} = \varepsilon_{11}\frac{\Delta p_1}{p_1} + \varepsilon_{12}\frac{\Delta p_2}{p_2} + \ldots + \varepsilon_{1n}\frac{\Delta p_n}{p_n} \tag{7}$$

$$\frac{\Delta q_2}{q_2} = \varepsilon_{21}\frac{\Delta p_1}{p_1} + \varepsilon_{22}\frac{\Delta p_2}{p_2} + \ldots + \varepsilon_{2n}\frac{\Delta p_n}{p_n} \tag{8}$$

$$\frac{\Delta q_n}{q_n} = \varepsilon_{n1}\frac{\Delta p_1}{p_1} + \varepsilon_{n2}\frac{\Delta p_2}{p_2} + \ldots + \varepsilon_{nn}\frac{\Delta p_n}{p_n} \tag{9}$$

If we now represent the introduction of a tax (subsidy) as a proportional change in the supply of the product taxed (subsidised), with τ_i being the tax (in euro, €) on good *i*, then from equations (7) to (9) the following supply functions emerge:

$$\frac{1}{\varepsilon_{11}}\frac{\Delta q_1}{q_1}-\frac{\Delta p_1}{p_1}-\frac{\varepsilon_{12}}{\varepsilon_{11}}\frac{\Delta p_2}{p_2}-\frac{\varepsilon_{13}}{\varepsilon_{11}}\frac{\Delta p_3}{p_3}-\ldots-\frac{\varepsilon_{1n}}{\varepsilon_{11}}\frac{\Delta p_n}{p_n}=-\frac{\tau_1}{p_1} \tag{10}$$

$$\frac{1}{\varepsilon_{22}}\frac{\Delta q_2}{q_2}-\frac{\varepsilon_{21}}{\varepsilon_{22}}\frac{\Delta p_1}{p_1}-\frac{\Delta p_2}{p_2}-\frac{\varepsilon_{23}}{\varepsilon_{22}}\frac{\Delta p_3}{p_3}-\ldots-\frac{\varepsilon_{2n}}{\varepsilon_{22}}\frac{\Delta p_n}{p_n}=-\frac{\tau_2}{p_2} \tag{11}$$

$$\frac{1}{\varepsilon_{nn}}\frac{\Delta q_n}{q_n}-\frac{\varepsilon_{n1}}{\varepsilon_{nn}}\frac{\Delta p_1}{p_1}-\frac{\varepsilon_{n2}}{\varepsilon_{nn}}\frac{\Delta p_2}{p_2}-\frac{\varepsilon_{n3}}{\varepsilon_{nn}}\frac{\Delta p_3}{p_3}-\ldots-\frac{\varepsilon_{n,n-1}}{\varepsilon_{nn}}\frac{\Delta p_{n-1}}{p_{n-1}}-\frac{\Delta p_n}{p_n}=-\frac{\tau_n}{p_n} \tag{12}$$

Assuming zero cross price elasticities of supply we have the following:

$$\frac{1}{\varepsilon_{11}}\frac{\Delta q_1}{q_1}-\frac{\Delta p_1}{p_1}=-\frac{\tau_1}{p_1} \tag{13}$$

$$\frac{1}{\varepsilon_{22}}\frac{\Delta q_2}{q_2}-\frac{\Delta p_2}{p_2}=-\frac{\tau_2}{p_2} \tag{14}$$

$$\frac{1}{\varepsilon_{nn}}\frac{\Delta q_n}{q_n}-\frac{\Delta p_n}{p_n}=-\frac{\tau_n}{p_n} \tag{15}$$

Equations (13) to (15) can be re-written as

$$\frac{\Delta p_i}{p_i}=\frac{1}{\varepsilon_{ii}}\frac{\Delta q_i}{q_i}+\frac{\tau_i}{p_i} \quad i=1\ldots n \tag{16}$$

If $\varepsilon_{11}=\infty$ then $\Delta p_1=\tau_1$. As in the case of implementing a tax the change in quantity (Δq_1) is negative when $\Delta p_1<\tau_1$.

For the case of *n* = 2, substituting equation (16) in the demand functions (4)-(6) gives the following:

$$\frac{\Delta q_1}{q_1}=\mu_{11}\left(\frac{1}{\varepsilon_{11}}\frac{\Delta q_1}{q_1}+\frac{\tau_1}{p_1}\right)+\mu_{12}\left(\frac{1}{\varepsilon_{22}}\frac{\Delta q_2}{q_2}+\frac{\tau_2}{p_2}\right)+\eta_1\frac{\Delta m}{m} \tag{17}$$

$$\frac{\Delta q_2}{q_2}=\mu_{21}\left(\frac{1}{\varepsilon_{11}}\frac{\Delta q_1}{q_1}+\frac{\tau_1}{p_1}\right)+\mu_{22}\left(\frac{1}{\varepsilon_{22}}\frac{\Delta q_2}{q_2}+\frac{\tau_2}{p_2}\right)+\eta_2\frac{\Delta m}{m} \tag{18}$$

Rearranging:

$$(1-\frac{\mu_{11}}{\varepsilon_{11}})\frac{\Delta q_1}{q_1}-\frac{\mu_{12}}{\varepsilon_{22}}\frac{\Delta q_2}{q_2}=\mu_{11}\frac{\tau_1}{p_1}+\mu_{12}\frac{\tau_2}{p_2}+\eta_1\frac{\Delta m}{m} \tag{19}$$

$$-\frac{\mu_{21}}{\varepsilon_{11}}\frac{\Delta q_1}{q_1}+(1-\frac{\mu_{22}}{\varepsilon_{22}})\frac{\Delta q_2}{q_2}=\mu_{21}\frac{\tau_1}{p_1}+\mu_{22}\frac{\tau_2}{p_2}+\eta_2\frac{\Delta m}{m} \tag{20}$$

It is also known that

$$\frac{\Delta m}{m}=-w_1\frac{\Delta P_1}{P_1}-w_2\frac{\Delta P_2}{P_2} \tag{21}$$

$$\frac{\Delta m}{m}=-w_1(\frac{1}{\varepsilon_{11}}\frac{\Delta q_1}{q_1}+\frac{\tau_1}{p_1})-w_2(\frac{1}{\varepsilon_{22}}\frac{\Delta q_2}{q_2}+\frac{\tau_2}{p_2}) \tag{22}$$

Using matrix notation and rearranging, the following is obtained:

$$\begin{bmatrix} 1-\frac{\mu_{11}-\eta_1 w_1}{\varepsilon_{11}} & -\frac{(\mu_{12}-\eta_1 w_2)}{\varepsilon_{22}} \\ -\frac{\mu_{21}-\eta_2 w_1}{\varepsilon_{11}} & 1-\frac{\mu_{22}-\eta_2 w_2}{\varepsilon_{22}} \end{bmatrix}\begin{bmatrix} \frac{\Delta q_1}{q_1} \\ \frac{\Delta q_2}{q_2} \end{bmatrix}=\begin{bmatrix} (\mu_{11}-\eta_1 w_1)\frac{\tau_1}{p_1}+(\mu_{12}-\eta_1 w_2)\frac{\tau_2}{p_2} \\ (\mu_{21}-\eta_2 w_1)\frac{\tau_1}{p_1}+(\mu_{22}-\eta_2 w_2)\frac{\tau_2}{p_2} \end{bmatrix} \tag{23}$$

So

$$\begin{bmatrix} \frac{\Delta q_1}{q_1} \\ \frac{\Delta q_2}{q_2} \end{bmatrix}=\begin{bmatrix} 1-\frac{\mu_{11}-\eta_1 w_1}{\varepsilon_{11}} & -\frac{(\mu_{12}-\eta_1 w_2)}{\varepsilon_{22}} \\ -\frac{\mu_{21}-\eta_2 w_1}{\varepsilon_{11}} & 1-\frac{\mu_{22}-\eta_2 w_2}{\varepsilon_{22}} \end{bmatrix}^{-1}\times\begin{bmatrix} (\mu_{11}-\eta_1 w_1)\frac{\tau_1}{p_1}+(\mu_{12}-\eta_1 w_2)\frac{\tau_2}{p_2} \\ (\mu_{21}-\eta_2 w_1)\frac{\tau_1}{p_1}+(\mu_{22}-\eta_2 w_2)\frac{\tau_2}{p_2} \end{bmatrix} \tag{24}$$

Equation (24) is used in the optimisation exercise to find the values for the constraints described in Section 4.2.

Note that, as it is assumed that $\varepsilon_{ii}=\infty$, the following is obtained:

$$\begin{bmatrix} \frac{\Delta q_1}{q_1} \\ \frac{\Delta q_2}{q_2} \end{bmatrix}=\begin{bmatrix} (\mu_{11}-\eta_1 w_1)\frac{\tau_1}{p_1}+(\mu_{12}-\eta_1 w_2)\frac{\tau_2}{p_2} \\ (\mu_{21}-\eta_2 w_1)\frac{\tau_1}{p_1}+(\mu_{22}-\eta_2 w_2)\frac{\tau_2}{p_2} \end{bmatrix} \tag{25}$$

The above equations are valid only for small changes in prices. When significant price changes are to be analysed, equation (25) must be executed n times so that $\Delta p_1 = \frac{\tau_1}{n}$ and $\Delta p_2 = \frac{\tau_2}{n}$. In this case, the analytical solution shown below in equations (26) and (27) exists.

$$q_1 + \Delta q_1 = q_1 (\frac{p_1 + \Delta p_1}{p_1})^{(\mu_{11} - \eta_1 w_1)} (\frac{p_2 + \Delta p_2}{p_2})^{(\mu_{12} - \eta_1 w_2)} \tag{26}$$

$$q_2 + \Delta q_2 = q_2 (\frac{p_1 + \Delta p_1}{p_1})^{(\mu_{21} - \eta_2 w_1)} (\frac{p_2 + \Delta p_2}{p_2})^{(\mu_{22} - \eta_2 w_2)} \tag{27}$$

4. Data and calculations

4.1 Data

The data used in this paper were collected by the company *CPS, Estudios de Mercado y Opinión S.L.* in January 2012 from 11 different retailers in 6 representative Spanish regions[2] for three types of household appliance: dishwashers, refrigerators and washing machines. All details and calculations of elasticity values are presented in Lucas and Galarraga (2015). The values reported are summarised in Table 1 below.

The values for the Hicksian elasticities are calculated from Slutsky's equation[3],

$$\mu_{ii} = \mu_{ii}^H - w_i \eta_i \tag{28}$$

where μ_{ii}^H stands for Hicksian elasticity. The values are shown in Table 2. These values are necessary to calculate the Compensated change in the demand for good i when there is a change in the price of good j in (3).

[2] These regions were Galicia, the Basque Country, Valencia, Seville, Madrid and Barcelona.
[3] See Varian (2010) for more details.

Table 1: Values used for the calculations

	Dishwashers				Refrigerators			Washing machines					
Parameter	**Case I**	**Case II**	**Case III**	**Case IV**	**Case I**	**Case II**	**Case III**	**Case I**	**Case II**	**Case III**	**Case IV**	**Case V**	**Case VI**
Quantities Labelled (L)	99,134	99,134	99,134	99,134	64,367	64,367	64,367	189,240	189,240	189,240	189,240	189,240	189,240
Quantities Other (O)	1,700,030	1,700,030	1,700,030	1,700,030	957,330	957,330	957,330	1,623,401	1,623,401	1,623,401	1,623,401	1,623,401	1,623,401
Prices L	501.46	501.46	501.46	501.46	770.90	770.90	770.90	497.25	497.25	497.25	497.25	497.25	497.25
Prices O	482.03	482.03	482.03	482.03	684.45	684.45	684.45	477.44	477.44	477.44	477.44	477.44	477.44
Exp. Share L	0.000096	0.000096	0.000096	0.000096	0.000096	0.000096	0.000096	0.000181	0.000181	0.000181	0.000181	0.000181	0.000181
Exp. Share O	0.001578	0.001578	0.001578	0.001578	0.001262	0.001262	0.001262	0.001492	0.001492	0.001492	0.001492	0.001492	0.001492
Own P elast of Demand L (Marshallian)	-2.04	-6.15	-10.26	-14.37	-1.71	-5.00	-8.28	-1.22	-3.28	-5.34	-7.40	-9.46	-11.52
Cross P elast of Demand L-O (Marshallian)	1.64	5.76	9.89	14.01	1.32	4.62	7.92	0.82	2.88	4.94	7.00	9.06	11.11
Cross P elast of Demand O-L (Marshallian)	0.1	0.35	0.6	0.85	0.1	0.35	0.6	0.1	0.35	0.6	0.85	1.1	1.35
Own P elast of Demand O (Marshallian)	-0.5	-0.75	-1	-1.25	-0.5	-0.75	-1	-0.5	-0.75	-1	-1.25	-1.5	-1.75
Income elast. L	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Income elast O	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Source: Lucas and Galarraga (2015)

Table 2: Hicksian elasticity estimates

	Dishwashers				Refrigerators			Washing machines					
Parameter	**Case I**	**Case II**	**Case III**	**Case IV**	**Case I**	**Case II**	**Case III**	**Case I**	**Case II**	**Case III**	**Case IV**	**Case V**	**Case VI**
Own P elast of Demand L	-2.04	-6.15	-10.26	-14.37	-1.71	-5.00	-8.29	-1.22	-3.29	-5.35	-7.41	-9.47	-11.53
Cross P elast of Demand L-O	1.65	5.77	9.89	14.01	1.32	4.62	7.92	0.82	2.88	4.94	7.00	9.06	11.12
Cross P elast of Demand O-L	0.10	0.35	0.60	0.85	0.10	0.35	0.60	0.10	0.35	0.60	0.85	1.10	1.35
Own P elast of Demand O	-0.50	-0.75	-1.00	-1.25	-0.50	-0.75	-1.00	-0.50	-0.75	-1.00	-1.25	-1.50	-1.75

Source: Own calculations

4.2 Optimisation

If the matrix $\mathbf{S}$ is now defined as:

$$\mathbf{S} = \begin{bmatrix} \mu^H{}_{1,1}\frac{q_1}{P_1} & \mu^H{}_{1,2}\frac{q_1}{P_2} & \ldots & \mu^H{}_{1,39}\frac{q_1}{P_{39}} \\ \mu^H{}_{2,1}\frac{q_2}{P_1} & \mu^H{}_{2,2}\frac{q_2}{P_2} & \ldots & \mu^H{}_{2,39}\frac{q_2}{P_{39}} \\ \mu^H{}_{3,1}\frac{q_3}{P_1} & \mu^H{}_{3,2}\frac{q_3}{P_2} & \ldots & \mu^H{}_{3,39}\frac{q_3}{P_{39}} \\ \ldots & \ldots & \ldots & \ldots \\ \mu^H{}_{39,1}\frac{q_{39}}{P_1} & \mu^H{}_{39,2}\frac{q_{39}}{P_2} & \ldots & \mu^H{}_{39,39}\frac{q_{39}}{P_{39}} \end{bmatrix} \tag{29}$$

where all elasticities are Hicksian, the DWL is:

$$DWL = -\frac{1}{2}\mathbf{x}'\mathbf{S}\mathbf{x} \tag{30}$$

where $\boldsymbol{x}' = [x_1 \quad x_2 \quad \ldots \quad]$ and $x_i = \Delta P_i = \tau_i$.

To minimise DWL, the following is defined:

$$\min_{\mathbf{x}} DWL(\mathbf{x}) \tag{31}$$

The following cases can now be analysed:

Case (a.1): Emission reduction target:

In this case an emission reduction target of any given percentage is imposed. This is done by setting constraints on how much emission there should be. If c_L and c_O are defined as electricity consumption for labelled and non-labelled (other) appliances and emi is set as the emission target, the DWL equation (30) can be minimised s.t.

$$(q_L \times c_L + q_O \times c_O) \times emi = (q_L + \Delta q_L) \times c_L + (q_O + \Delta q_O) \times c_O \tag{32}$$

Note that equations (26) and (27) are used to find the appropriate values for Δq_L and Δq_O in this constraint.

Case (a.2): Emission reduction target:

If it is now additionally imposed that the subsidy must be positive or zero, the following constraints emerge:

$$(q_L \times c_L + q_O \times c_O) \times emi = (q_L + \Delta q_L) \times c_L + (q_O + \Delta q_O) \times c_O \tag{33}$$

$$x_L \leq 0 \tag{34}$$

where x_L and x_O are taxes (subsidies) when they have a positive (negative) value.

Note that as there are only equations for two unknowns, when two restrictions are used, the DWL is not really being minimised: rather, the resulting DWL is being calculated. This is a caveat of the data used for this analysis but not of the methodology as when more information becomes available the minimisation exercise will be easy to perform.

Case (b): No deficit

If it is required that the resulting policy generate no deficit, the constraints are as follows:

$$x_L \times (q_L + \Delta q_L) + x_O \times (q_O + \Delta q_O) = 0 \tag{35}$$

$$x_L = sub \tag{36}$$

where $sub \in \{5,10,15,...\}$.

Many other exercises can be conducted with this method, such as setting the number of efficient or non-efficient appliances at certain levels, etc. The case for restricting these numbers is set out below.

Case (c): Reducing the number of non-efficient appliances

We now impose a pre-set percentage reduction in the number of non-efficient appliances. To achieve a reduction red is defined as the total reduced target figure, that is, for a 1% reduction the variable $red = 0.99$. In this case DWL is being minimised, s.t.

$$q_O \times red = (q_O + \Delta q_O) \tag{37}$$

Case (d): Increasing the number of efficient appliances

If instead the goal is to increase the total number of appliances, the variable inc is set to the new desired level, e.g. for 1%, $inc = 1.01$. Again DWL is being minimised, s.t.

$$q_L \times inc = (q_L + \Delta q_L) \tag{38}$$

5. Results

Several different results can be obtained with this model depending on the policy goal pursued by the authorities, as described in the previous section. All detailed results are available upon request. Here we report only those referring to **Case I** in **Table 1**.

To that end, the following policy goals are defined:

5.1 Emission reduction target

When the purpose of the policy is to save energy, and consequently reduce emissions, the following results are obtained (Tables 3-5).

Table 3: Results for the case of dishwashers with energy savings (a.1)

Dishwashers Case I				
Emission reduction	**1%**	**5%**	**10%**	**15%**
Subsidy (L)	-11.25	-61.77	-138.47	-233.09
Tax (O)	12.28	66.03	145.40	241.79
DWL	111,541.03	3,227,019.93	15,662,007.62	4,3343,358.86
qL0	99,134	99,134	99,134	99,134
qO0	1,700,030	1,700,030	1,700,030	1,700,030
qL1	98,750.38	96,603.13	92,995.21	88,784.08
qO1	1,682,477.11	1,612,822.78	1,526,594.89	1,440,915.47
pL0	501.46	501.46	501.46	501.46
pO0	482.03	482.03	482.03	482.03
pL1	512.71	563.23	639.93	734.55
pO1	494.31	548.06	627.43	723.82
Unit consumption L	260.91	260.91	260.91	260.91
Unit consumption O	286.54	286.54	286.54	286.54
Consumption I (MWh/year)	512,992	512,992	512,992	512,992
Consumption F (MWh/year)	507,862	487,343	461,694	436,045
Δ Consumption (MWh/year)	-5,130	-25,649	-51,298	-76,947
Δ Consumption (%)	-1.00%	-5.00%	-10.00%	-15.00%
Δ Domestic Appliances	-17,936	-89,738	-179,574	-269,464
Net tax+subsidy	-21,775,086	-112,465,119	-234,846,052	-369,096,543

Note that in this case the results suggest negative subsidies for labelled goods, that is, taxes for both labelled and non-labelled goods. This is because the most effective way to reduce emissions is by taxing both types of goods. However, when DWL is minimised the taxes on labelled goods are lower than on regular ones. In this case the government obtains revenues of 235 mill euro while reducing emissions by 10%, but the total number of appliances is reduced by 179,574 units and consequently there are energy savings to the tune of 51,298 MWh/year. This policy goal requires a large DWL to be generated, almost 16 mill euro. Figure 1 shows tax rates applied to labelled and non-labelled dishwashers as well as the change in quantities.

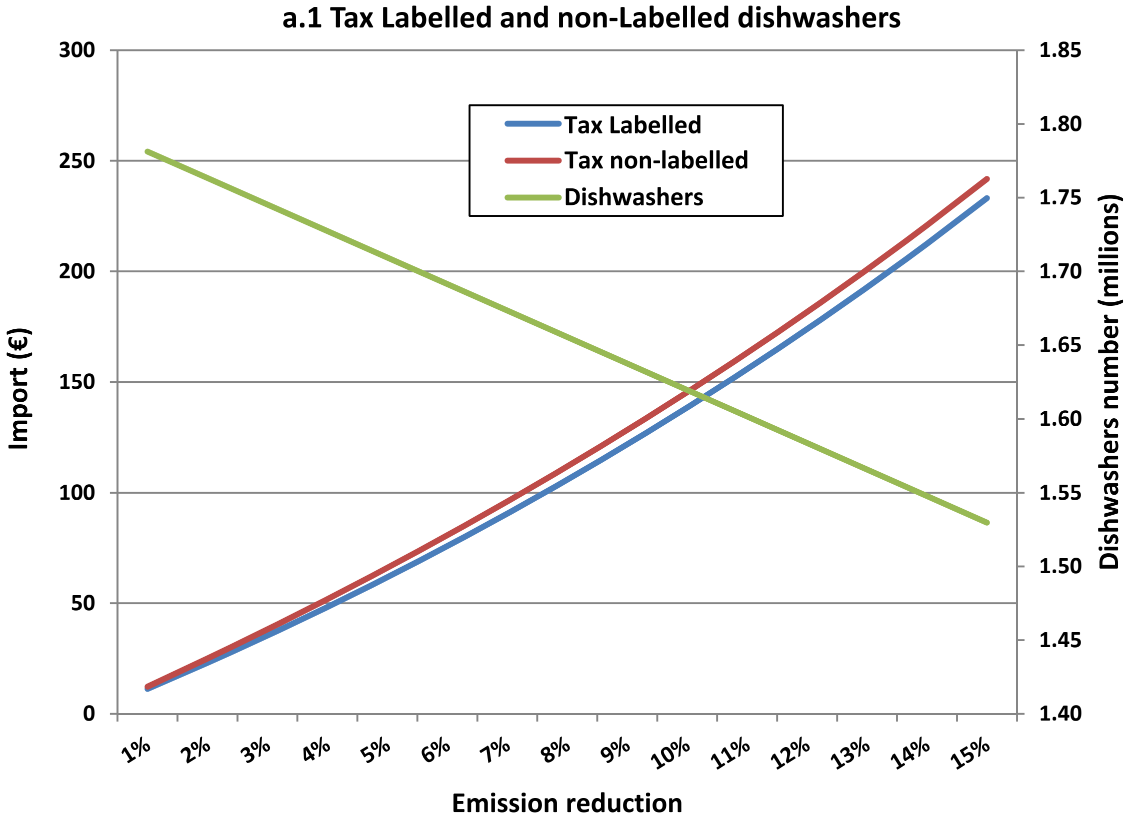

Figure 1: Dishwashers Subsidy and tax.

Figure 2 shows that DWL increases rapidly as emission reduction goals get higher.

Results for the case of refrigerators are similar to the case of dishwashers, as shown in Table 4. However, in this case, the differences in consumption between labelled and non-labelled appliances are significantly greater. Results for the case of washing machines are shown in Table 5.

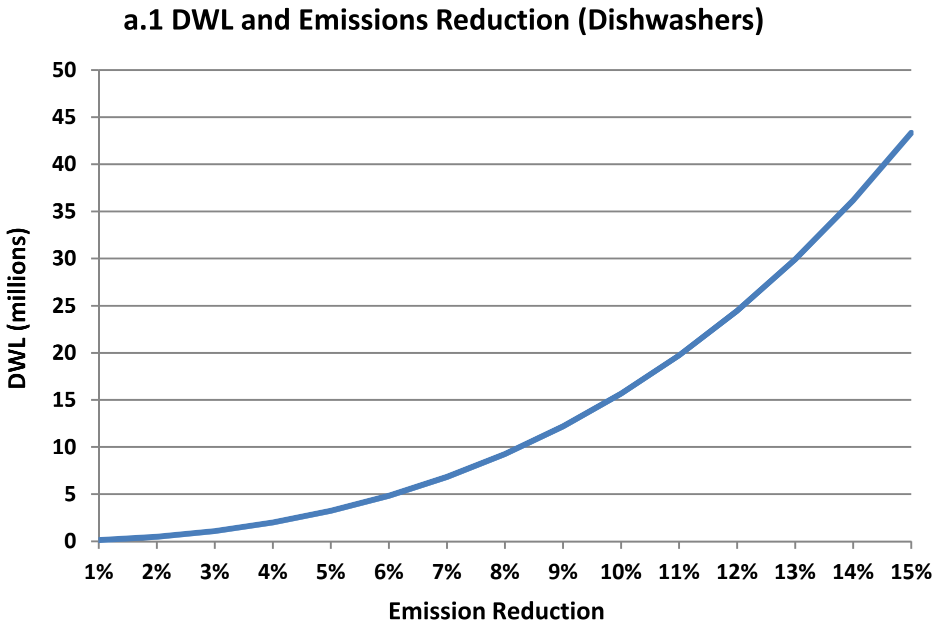

Figure 2: DWL and emissions reduction a.1 Dishwashers

Table 4: Results for the case of refrigerators with energy savings (a.1)

Refrigerators Case I				
Emission reduction	**1%**	**5%**	**10%**	**15%**
Subsidy (L)	-16.01	-88.67	-200.51	-339.83
Tax (O)	17.45	93.84	206.70	343.80
DWL	89,977.15	2,605,163.91	12,653,800.16	35,040,349.55
qL0	64,367	64,367	64,367	64,367
qO0	957,330	957,330	957,330	957,330
qL1	64,236.70	63,277.15	61,347.04	58,887.62
qO1	947,289.91	907,528.13	858,490.29	809,933.72
pL0	770.9	770.9	770.9	770.9
pO0	684.45	684.45	684.45	684.45
pL1	786.91	859.57	971.41	1,110.73
pO1	701.90	778.29	891.15	1,028.25
Unit consumption L	235.25	235.25	235.25	235.25
Unit consumption O	300.84	300.84	300.84	300.84
Consumption I (MWh/year)	303,145	303,145	303,145	303,145
Consumption F (MWh/year)	300,094	287,907	272,700	257,514
Δ Consumption (MWh/year)	-3,051	-15,239	-30,445	-45,632
Δ Consumption (%)	-1.01%	-5.03%	-10.04%	-15.05%
Δ Domestic Appliances	-10,170	-50,892	-101,860	-152,876
Net tax+subsidy	-17,555,908	-90,773,260	-189,752,254	-298,465,110

Table 5: Results for the case of washing machines with energy savings (a.1)

Washing machines Case I				
Emission reduction	**1%**	**5%**	**10%**	**15%**
Subsidy (L)	-11.18	-61.00	-136.19	-228.78
Tax (O)	12.23	65.70	144.58	240.31
DWL	111,391.12	3,222,020.56	15,634,996.92	43,262,439.3
qL0	189,240	189,240	189,240	189,240
qO0	1,623,401	1,623,401	1,623,401	1,623,401
qL1	188,032.93	182,629.67	174,925.99	166,526.80
qO1	1,606,543.85	1,539,638.03	1,456,869.21	1,374,732.78
pL0	497.25	497.25	497.25	497.25
pO0	477.44	477.44	477.44	477.44
pL1	508.43	558.25	633.44	726.03
pO1	489.67	543.14	622.02	717.75
Unit consumption L	187.72	187.72	187.72	187.72
Unit consumption O	205.34	205.34	205.34	205.34

Consumption I (MWh/year)	368,873	368,873	368,873	368,873
Consumption F (MWh/year)	365,185	350,433	331,991	313,548
Δ Consumption (MWh/year)	-3,688	-18,441	-36,883	-55,325
Δ Consumption (%)	-1.00%	-5.00%	-10.00%	-15.00%
Δ Domestic Appliances	-18,064	-90,373	-180,846	-271,381
Net tax+subsidy	-21,745,411	-112,289,148	-234,453,510	-368,461,581

A further constraint could of course be added to the analysis to guarantee that subsidises are positive or zero. The latter applies to the case of only penalising non-efficient appliances while offering no direct incentives for efficient ones. Indirect incentives would exist however due to changes in relative prices. This is the case (a.2) in section 4.2. We then get the following results (Tables 6-8).

Table 6: Results for the case of dishwashers with energy savings (a.2)

Dishwashers Case I				
Emission reduction	**1%**	**5%**	**10%**	**15%**
Subsidy (L)	0	0	0	0
Tax (O)	12.60	70.46	168.08	331.65
DWL	139,755.65	4,371,175.76	24,877,179.88	96,855,782.59
qL0	99,134	99,134	99,134	99,134
qO0	1,700,030	1,700,030	1,700,030	1,700,030
qL1	103,439.32	124,122.37	162,290.95	234,909.27
qO1	1,678,213.64	1,587,800.57	1,463,586.89	1,308,049.36
pL0	501.46	501.46	501.46	501.46
pO0	482.03	482.03	482.03	482.03
pL1	501.46	501.46	501.46	501.46
pO1	494.63	552.48	650.11	813.68
Unit consumption L	260.91	260.91	260.91	260.91
Unit consumption O	286.54	286.54	286.54	286.54
Consumption I (MWh/year)	512,992	512,992	512,992	512,992
Consumption F (MWh/year)	507,864	487,353	461,720	436,099
Δ Consumption (MWh/year)	-5,128	-25,639	-51,272	-76,893
Δ Consumption (%)	-1.00%	-5.00%	-9.99%	-14.99%
Δ Domestic Appliances	-17,511	-87,241	-173,286	-256,205
Net tax+subsidy	-21,141,946	-111,868,580	-245,998,308	-433,810,386

The results in Table 6 show a greater DWL than those in Table 3. This is because higher taxes on non-labelled appliances (dishwashers) are required to achieve the same emission reduction. That is for a 10% emission reduction, a tax of €168.08 is needed to make the price of non-efficient appliances higher than the price of labelled ones. Consequently, the quantity of labelled dishwashers will increase while regular ones will decrease. Overall, a 10% reduction target reduces the total number of appliances by 173,286, generating an energy saving of 51,272 MWh/year. Important tax revenues are also collected.

Tables 7 and 8 show the results for refrigerators and washing machines. Equivalent results are obtained in both cases.

Table 7: Results for the case of refrigerators with energy savings (a.2)

Refrigerators Case I				
% Emissions	**0,99**	**0.95**	**0.90**	**0.85**
Subsidy (L)	0	0	0	0
Tax (O)	17.72	98.18	228.88	420.19
DWL	109,639.32	3,367,369.52	18,299,467.92	61,674,844.42
qL0	64,367	64,367	64,367	64,367
qO0	957,330	957,330	957,330	957,330
qL1	66,575.30	76,826.24	94,198.27	121,078.10
qO1	945,163.51	895,208.46	828,619.90	753,386.27
pL0	770.9	770.9	770.9	770.9
pO0	684.45	684.45	684.45	684.45
pL1	770.9	770.9	770.9	770.9
pO1	702.17	782.63	913.33	1,104.64
Unit consumption L	235.25	235.25	235.25	235.25
Unit consumption O	300.84	300.84	300.84	300.84
Consumption I (MWh/year)	303,145	303,145	303,145	303,145
Consumption F (MWh/year)	300,005	287,388	271,442	255,132
Δ Consumption (MWh/year)	-3,141	-15,758	-31,703	-48,013
Δ Consumption (%)	-1.04%	-5.20%	-10.46%	-15.84%
Δ Domestic Appliances	-9,958	-49,662	-98,879	-147,233
Net tax+subsidy	-16,744,778	-87,893,926	-189,654,822	-316,563,639

Of course, as indicated above, when this analysis is conducted for only two variables no real optimisation is taking place. This caveat applies to the analysis but not the method itself, which is designed to work with several variables and constraints. Logically, the more variables are used the greater the constraints that can be added.

Table 8: Results for the case of washing machines with energy savings (a.2)

Washing machines Case I				
% Emissions	**0.99**	**0.95**	**0.90**	**0.85**
Subsidy (L)	0	0	0	0
Tax (O)	13.09	72.58	168.74	304.97

DWL	145,405.88	4,472,964.30	24,173,927.29	78,968,986.87
qL0	189,240	189,240	189,240	189,240
qO0	1,623,401	1,623,401	1,623,401	1,623,401
qL1	193,499.09	212,618.32	242,768.17	284,169.62
qO1	1,601,573.67	1,512,370.49	1,395,182.88	1,267,764.61
pL0	497.25	497.25	497.25	497.25
pO0	477.44	477.44	477.44	477.44
pL1	497.25	497.25	497.25	497.25
pO1	490.53	550.02	646.18	782.41
Unit consumption L	187.72	187.72	187.72	187.72
Unit consumption O	205.34	205.34	205.34	205.34
Consumption I (MWh/year)	368,873	368,873	368,873	368,873
Consumption F (MWh/year)	365,191	350,463	332,059	313,667
Δ Consumption (MWh/year)	-3,683	-18,410	-36,814	-55,206
Δ Consumption (%)	-1.00%	-4.99%	-9.98%	-14.97%
Δ Domestic Appliances	-17,568	-87,652	-174,690	-260,707
Net tax+subsidy	-20,959,154	-109,772,042	-235,418,494	-386,636,403

5.1 No deficit or balanced budget

If the objective of the public authority is not to generate any deficit as a result of the policy, the following combinations of taxes and subsidies can be used to minimise DWL while generating some energy saving (Tables 9-11).

Table 9: Results for the case of dishwasher under budget neutrality

Dishwashers Case I								
Subsidy	20	45	75	85	90	95	100	105
Tax	1.28	3.26	6.37	7.63	8.32	9.04	9.81	10.62
DWL	90,926.27	468,108.3	1,333,915	1,730,894	1,951,177	2,186,544	2,437,470	2,704,484
qL0	99,134	99,134	99,134	99,134	99,134	99,134	99,134	99,134
qO0	1,700,030	1,700,030	1,700,030	1,700,030	1,700,030	1,700,030	1,700,030	1,700,030
qL1	108,204.6	121,477.2	141,060.7	148,703.7	152,772.3	157,019.1	161,455.3	166,093
qO1	1,690,881	1,678,459	1,661,769	1,655,682	1,652,525	1,649,288	1,645,966	1,642,554
pL0	501.46	501.46	501.46	501.46	501.46	501.46	501.46	501.46
pO0	482.03	482.03	482.03	482.03	482.03	482.03	482.03	482.03
pL1	481.46	456.46	426.46	416.46	411.46	406.46	401.46	396.46
pO1	483.31	485.29	488.40	489.66	490.35	491.07	491.84	492.65
Unit consumption L	260.91	260.91	260.91	260.91	260.91	260.91	260.91	260.91
Unit consumption O	286.54	286.54	286.54	286.54	286.54	286.54	286.54	286.54

Consumption I (MWh/year)	512,992	512,992	512,992	512,992	512,992	512,992	512,992	512,992
Consumption F (MWh/year)	512,737	512,640	512,967	513,217	513,374	513,555	513,760	513,993
Δ Consumption (MWh/year)	-255	-351	-24	226	383	563	769	1,001
Δ Domestic appliances	-78	772	3,666	5,222	6,134	7,143	8,257	9,483
Net tax+subsidy	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

When budget neutrality is envisaged, a €90 subsidy on labelled appliance requires a €8.32 tax on non-labelled ones. This policy increases the total number of appliances by 6,134 as the increase in labelled appliances is greater than the decrease in non-labelled ones. As a consequence, there will an increase energy consumption of 383 MWh/year (Table 9). Other combinations of taxes and subsidises are also presented in Table 9. Tables 10 and 11 show results for the cases of refrigerators and washing machines along very similar lines. DWL is generated as a result of this combination of policy instruments.

Table 10: Results for the case of refrigerators under budget neutrality

Refrigerators Case I								
Subsidy	20	45	75	85	90	95	100	105
Tax	1.41	3.40	6.17	7.20	7.74	8,29	8.86	9.44
DWL	32,849.48	168,035	473,447	611,307.5	687,207.8	767,825.9	853,218.8	943,447
qL0	64,367	64,367	64,367	64,367	64,367	64,367	64,367	64,367
qO0	957,330	957,330	957,330	957,330	957,330	957,330	957,330	957,330
qL1	67,518.38	71,828.49	77,629.59	79,736.78	80,826.04	81,940.1	83,079.77	84,245.9
qO1	953,830.9	949,230.8	943,337.2	941,271.9	940,218.9	939,151.8	938,070.3	936,973.9
pL0	770.9	770.9	770.9	770.9	770.9	770.9	770.9	770.9
pO0	684.45	684.45	684.45	684.45	684.45	684.45	684.45	684.45
pL1	750.9	725.9	695.9	685.9	680.9	675.9	670.9	665.9
pO1	685.86	687.85	690.62	691.65	692.19	692.74	693.31	693.89
Unit consumption L	235.25	235.25	235.25	235.25	235.25	235.25	235.25	235.25
Unit consumption O	300.84	300.84	300.84	300.84	300.84	300.84	300.84	300.84
Consumption I (MWh/year)	303,145	303,145	303,145	303,145	303,145	303,145	303,145	303,145
Consumption F (MWh/year)	302,834	302,464	302,056	301,930	301,870	301,811	301,754	301,698
Δ Consumption (MWh/year)	-311	-681	-1,090	-1,215	-1,276	-1,335	-1,392	-1,447
Δ Domestic appliances	-348	-638	-730	-688	-652	-605	-547	-477
Net tax+subsidy	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Table 11: Results for the case of washing machines under budget neutrality

Washing machines Case I								
Subsidy	20	45	75	85	90	95	100	105
Tax	2.48	6.05	11.19	13.17	14.21	15.28	16.41	17,58
DWL	114,592.5	591,695.2	1,691,055	2,195,890	2,476,057	2,775,373	3,094,381	3,433,671
qL0	189,240	189,240	189,240	189,240	189,240	189,240	189,240	189,240
qO0	1,623,401	1,623,401	1,623,401	1,623,401	1,623,401	1,623,401	1,623,401	1,623,401
qL1	199,844.8	214,759.1	235,631.5	243,454.2	247,550.5	251,778	256,142.9	260,652
qO1	1,612,570	1,597,985	1,578,672	1,571,724	1,568,143	1,564,487	1,560,754	1,556,939
pL0	497.25	497.25	497.25	497.25	497.25	497.25	497.25	497.25
pO0	477.44	477.44	477.44	477.44	477.44	477.44	477.44	477.44
pL1	477.25	452.25	422.25	412.25	407.25	402.25	397.25	392.25
pO1	479.92	483.49	488.63	490.61	491.65	492.73	493.85	495.01
Unit consumption L	187.72	187.72	187.72	187.72	187.72	187.72	187.72	187.72
Unit consumption O	205.34	205.34	205.34	205.34	205.34	205.34	205.34	205.34
Consumption I (MWh/year)	368,873	368,873	368,873	368,873	368,873	368,873	368,873	368,873
Consumption F (MWh/year)	368,640	368,445	368,397	368,439	368,473	368,516	368,568	368,631
Δ Consumption (MWh/year)	-233	-429	-476	-434	-401	-358	-305	-242
Δ Domestic appliances	-226	103	1,662	2,537	3,052	3,624	4,255	4,950
Net tax+subsidy	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

5.2 Monitoring the number of efficient and non-efficient appliances in the market

Of course this analysis can work either way, as policy combinations can be sought for increasing the number of energy efficient appliances or reducing the number of non-efficient ones. The ideal condition would be to keep the total number of appliances constant while increasing the share of efficient ones and reducing the share of non-efficient ones. This can be done with the method explained here. As highlighted above, with the data available this means introducing two constraints and thus no real minimisation takes place: rather just the DWL is calculated. This is a caveat imposed by the data and not by the method. Results for such case are shown in Tables 12-14.

Table 12: Results for the case of dishwashers with total number constant

Dishwashers Case I								
Subsidy	20	45	75	85	90	95	100	105
Tax	1.22	3.84	9.37	12.06	13.61	15.33	17.23	19.33
DWL	90,418.69	480,718.58	1,452,120.3	1,935,301.1	2,215,065.38	2,524,007.3	2,865,675.783	3,244,421.31
qL0	99,134	99,134	99,134	99,134	99,134	99,134	99,134	99,134
qO0	1,700,030	1,700,030	1,700,030	1,700,030	1,700,030	1,700,030	1,700,030	1,700,030
qL1	108,183.7	121,719.06	142,495.1	150,925.65	155,500.12	160,344.93	165,487.64	170,960.28
qO1	1,690,980	1,677,444.9	1,656,668.9	1,648,238.4	1,643,663.88	1,638,819.1	1,633,676.36	1,628,203,72
pL0	501.46	501.46	501.46	501.46	501.46	501.46	501.46	501.46
pO0	482.03	482.03	482.03	482.03	482.03	482.03	482.03	482.03
pL1	481.46	456.46	426.46	416.46	411.46	406.46	401.46	396.46
pO1	483.25	485.87	491.40	494.091	495.64	497.36	499.26	501.36
Unit consumption L	260.91	260.91	260.91	260,91	260.91	260.91	260.91	260.91
Unit consumption O	286.54	286.54	286.54	286,54	286.54	286.54	286.54	286.54
Consumption I (MWh/year)	512,992	512,992	512,992	512,992	512,992	512,992	512,992	512,992
Consumption F (MWh/year)	512,760	512,413	511,880	511,664	511,547	511,423	511,291	511,151
Δ Consumption (MWh/year)	-232	-579	-1,111	-1,327	-1,445	-1,569	-1,701	-1,841
Δ Domestic appliances	0	0	0	0	0	0	0	0
Net tax+subsidy	94,959	-969,049	-4,843,151	-7,051,304	-8,383,617	-9,891,284	-11,595,312	-13,520,411

When the number of total appliances is to be kept constant and a €90 subsidy is applied to labelled dishwashers, a €13.61 tax is required for non-efficient ones. This combination enables some energy to be saved, with the consequent reduction in emissions. In this situation, some tax revenue is generated for the public authority as the taxes collected offset the subsidies given. In this situation, the DWL increases exponentially with the size of the subsidy.

Figure 3 shows the effect of substituting non-labelled appliances by labelled ones as the size of the subsidy increases.

In the cases of refrigerators and dishwashers the results shown in Tables 13 and 14 are obtained. The total number of appliances has been kept constant, which will generate some DWL and energy savings as a result of the reduction in non-efficient appliances being greater than the increase in labelled ones. This policy will also generate a positive tax burden for the case of refrigerators and some revenues for most of the combinations in the case of washing machines.

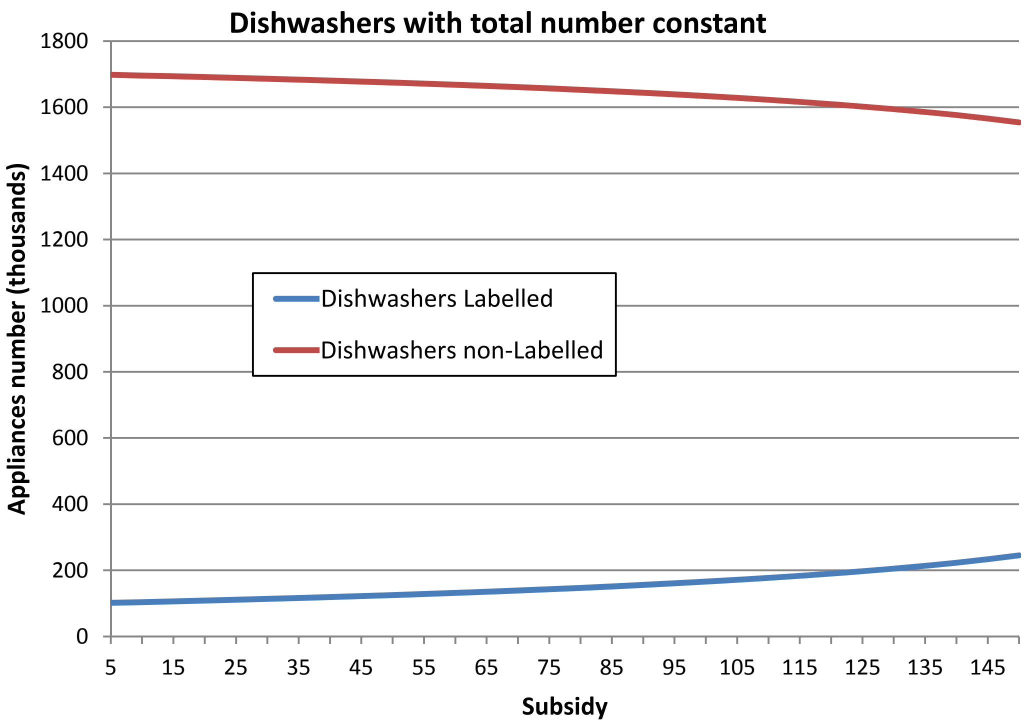

Figure 3: Substitution of non-labelled appliances by labelled ones

Table 13: Results for the case of refrigerators with total number constant

Refrigerators Case I								
Subsidy	20	45	75	85	90	95	100	105
Tax	0.80	2.25	4.81	5.90	6.50	7.13	7.80	8.52
DWL	30,849.01	159,320.6	455,538.24	591,649.15	667,208.82	747,950.64	834,023.93	925,591.28
qL0	64,367	64,367	64,367	64,367	64,367	64,367	64,367	64,367
qO0	957,330	957,330	957,330	957,330	957,330	957,330	957,330	957,330
qL1	67,438.64	71,669.79	77,427.636	79,539.20	80,635.27	81,759.61	82,913.38	84,097.79
qO1	954258.4	950,027.2	944,269.36	942,157.8	941,061.73	939,937.39	938,783.62	937,599.21
pL0	770.9	770.9	770.9	770.9	770.9	770.9	770.9	770.9
pO0	684.45	684.45	684.45	684.45	684.45	684.45	684.45	684.45
pL1	750.9	725.9	695.9	685.9	680.9	675.9	670.9	665.9
pO1	685.25	686.70	689.26	690.35	690.95	691.58	692.25	692.97
Unit consumption L	235.25	235.25	235.25	235.25	235.25	235.25	235.25	235.25
Unit consumption O	300.84	300.84	300.84	300.84	300.84	300.84	300.84	300.84
Consumption I (MWh/year)	303,145	303,145	303,145	303,145	303,145	303,145	303,145	303,145
Consumption F (MWh/year)	302,944	302,667	302,289	302,150	302,078	302,005	301,929	301,851
Δ Consumption (MWh/year)	-201	-479	-857	-995	-1,067	-1,141	-1,216	-1,294
Δ Domestic appliances	0	0	0	0	0	0	0	0
Net tax+subsidy	583,496	1,084,217	1,264,726	1,200,443	1,141,395	1,063,182	964,809	845,213

Table 14: Results for the case of washing machines with total number constant

Washing machines Case I								
Subsidy	20	45	75	85	90	95	100	105
Tax	2,31	6.13	12.56	15.30	16.80	18,41	20.12	21.95
DWL	112,800,7	593,692.04	1,752,067.6	2,306,590.3	2,620,697.3	2,961,468.8	3,330,757.6	3,730,683.9
qL0	189,240	189,240	189,240	189,240	189,240	189,240	189,240	189,240
qO0	1,623,401	1,623,401	1,623,401	1,623,401	1,623,401	1,623,401	1,623,401	1,623,401
qL1	199,786.8	214,788.22	236,173.50	244,324.44	248,625.58	253,089.43	257,726.21	262,547.14
qO1	1,612,854	1,597,852.8	1,576,467.5	1,568,316.6	1,564,015.4	1,559,551.6	1,554,914.8	1,550,093.9
pL0	497.25	497.25	497.25	497.25	497.25	497.25	497.25	497.25
pO0	477.44	477.44	477.44	477.44	477.44	477.44	477.44	477.44
pL1	477.25	452.25	422.25	412.25	407.25	402.25	397.25	392.25
pO1	479.75	483.57	490.00	492.74	494.24	495.85	497.56	499.39
Unit consumption L	187.72	187.72	187.72	187.72	187.72	187.72	187.72	187.72
Unit consumption O	205.34	205.34	205.34	205.34	205.34	205.34	205.34	205.34
Consumption I (MWh/year)	368,873	368,873	368,873	368,873	368,873	368,873	368,873	368,873
Consumption F (MWh/year)	368,687	368,423	368,046	367,903	367,827	367,748	367,667	367,582
Δ Consumption (MWh/year)	-186	-450	-827	-971	-1,046	-1,125	-1,207	-1,292
Δ Domestic appliances	0	0	0	0	0	0	0	0
Net tax+subsidy	270,791	-125,315	-2,087,789	-3,223,917	-3,903,604	-4,665,620	-5,516,684	-6,464,253

If the model is now required to minimise, by imposing only one restriction, and increase the total number of labelled appliances in the market the results shown in Tables 15-17 are obtained.

Table 15: Results for increasing the number of labelled dishwashers

Dishwashers Case I				
% Effic. Appliances	**1%**	**5%**	**10%**	**15%**
Subsidy	2.44	11.83	22.85	33.15
Tax	0.00	0.00	0.00	0.00
DWL	1,198.25	28,268.62	105,460.83	221,939.70
qL0	99,134	99,134	99,134	99,134
qO0	1,700,030	1,700,030	1,700,030	1,700,030
qL1	100,125.34	104,090.7	109,047.4	114,004.1
qO1	1,699,202,83	1,695,977,91	1,692,123.36	1,688,448.37
pL0	501.46	501.46	501.46	501.46
pO0	482.03	482.03	482.03	482.03
pL1	499.02	489.63	478.61	468.31
pO1	482.03	482.03	482.03	482.03
Unit consumption L	260.91	260.91	260.91	260.91
Unit consumption O	286.54	286.54	286.54	286.54
Consumption I (MWh/year)	512,992	512,992	512,992	512,992
Consumption F (MWh/year)	513,013	513,124	513,313	513,553
Δ Consumption (MWh/year)	22	132	321	561
Δ Consumption (%)	0.00%	0.03%	0.06%	0.11%
Δ Domestic appliances	164	905	2,007	3,288
Net Tax+subsidy	243,857	1,231,350	2,491,600	3,778,812

The case of dishwashers is shown in Table 15. A 10% increase in labelled appliances can be achieved with a net expenditure of €2.49 mill in subsidies. This incentivises an increase of almost 10,000 units of labelled appliances while reducing the number of non-efficient ones by almost 8,000. There will be an increase in energy consumption (321 MW/year) as the increase in the number of efficient dishwasher will outweigh the energy savings of reducing non-efficient ones.

Table 16: Results for increasing the number of labelled refrigerators

Refrigerators Case I				
% Effic. Appliances	**1%**	**5%**	**10%**	**15%**
Subsidy	4.46	21.63	41.68	60.34
Tax	0.00	0.00	0.00	0.00
DWL	1,424.28	33,479.23	124,362.402	260,650.15
qL0	64,367	64,367	64,367	64,367
qO0	957,330	957,330	957,330	957,330

qL1	65,010.67	67,585.35	70,803.7	74,022.05
qO1	956,774.82	954,610.82	952,025.35	949,561.38
pL0	770.9	770.9	770.9	770.9
pO0	684.45	684.45	684.45	684.45
pL1	766.44	749.27	729.22	710.55
pO1	684.45	684.45	684.45	684.45
Unit consumption L	235.25	235.25	235.25	235.25
Unit consumption O	300.84	300.84	300.84	300.84
Consumption I (MWh/year)	303,145	303,145	303,145	303,145
Consumption F (MWh/year)	303,130	303,085	303,064	303,080
Δ Consumption (MWh/year)	-16	-61	-82	-66
Δ Consumption (%)	-0.01%	-0.02%	-0.03%	-0.02%
Δ Domestic appliances	88	499	1,132	1,886
Net Tax+subsidy	289,993	1,461,659	2,951,252	4,466,794

Finally, Tables 16 and 17 show similar results for the other two types of appliances.

Table 17: Results for increasing the number of labelled washing machines

Washing machines Case I				
% Effic. Appliances	**1%**	**5%**	**10%**	**15%**
Subsidy	4.02	19.43	37.24	53.64
Tax	0.00	0.00	0.00	0.00
DWL	3,773.50	87,904.66	323,062.63	670,302.52
qL0	189,240	189,240	189,240	189,240
qO0	1,623,401	1,623,401	1,623,401	1,623,401
qL1	191,132.4	198,702	208,164	217,626
qO1	1,622,083.17	1,616,949.427	1,610,821.92	1,604,988.53
pL0	497.25	497.25	497.25	497.25
pO0	477.44	477.44	477.44	477.44
pL1	493.23	477.83	460.01	443.61
pO1	477.44	477.44	477.44	477.44
Unit consumption L	187.72	187.72	187.72	187.72
Unit consumption O	205.34	205.34	205.34	205.34
Consumption I (MWh/year)	368,873	368,873	368,873	368,873
Consumption F (MWh/year)	368,958	369,325	369,843	370,421
Δ Consumption (MWh/year)	85	451	969	1,548
Δ Consumption (%)	0.02%	0.12%	0.26%	0.42%
Δ Domestic appliances	575	3,010	6,345	9,974
Net Tax+subsidy	769,259	3,859,888	7,752,030	11,673,812

6. Conclusions

While there is plenty of economic literature that analyses the impact of taxes and subsidies for the promotion of energy efficiency, less work has been put into understanding the use of rebates for goods bearing efficiency labels, and much less for the combination of taxes and subsidies in a Bonus-Malus (or Feebate) type scheme.

The paper presented here contributes to the literature on feebates by building on the policy recommendation by Galarraga et al (2013) to design a Bonus-Malus scheme to promote energy efficient appliances in Spain. A sophisticated method is developed in the paper to guide the policy design phase for these and any other goods for which a Feebate scheme is to be designed. This method enables the right combination of taxes and subsidies to be set while minimising the dead weight loss generated by the policy instrument, with certain additional policy constraints. The constraints could be anything from budget neutrality to emission reduction targets, energy serving targets or many others.

We illustrate the use of the method with the cases of dishwashers, refrigerators and washing machines in the Spanish market. We show values for taxes and subsidies that can be used for several cases.

The results shown here further support the design and implementation of Bonus-Malus schemes to promote energy efficiency and show how this can be done effectively.

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